TECHNOLOGY ROADMAP

MEETING THE SHIPBOARD INTERNAL CARGO MOVEMENT CHALLENGE

Consensus Recommendations of the U.S. Shipbuilding Industry

Developed by the National Shipbuilding Research Program

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1. FOREWORD

The Navy-Marine Corps strategy for the 21st century is defined in *Naval Power 21…A Naval Vision*, and *Naval Transformation Roadmap, Power and Access…From the Sea.* An essential element of the strategy involves the concept of Sea Basing to provide for sustainable global projection of American power. Sea Basing enhances maneuver ashore by providing advanced command and control; long range, high volume, precise fire support; and vital logistical support from the sea. The indefinite sustainment offered by Sea Basing is critical in anti-access situations where there are no U.S. advance bases, friendly ports, or airfields. The final report of the Defense Science Board Task Force on Sea Basing discusses the overall DoD needs for Sea Basing in detail.

The Office of Naval Research provides Science and Technology (S&T) support for Naval Power 21 through a series of Future Naval Capability (FNC) investments. ONR's Expeditionary Logistics FNC is the vehicle used to fund S&T in ship design concepts and technology developments to enable sea basing: The ExLog FNC addresses the end-to-end challenges, including:

- Logistics planning and system-wide visibility
- Ship-to-Ship cargo movement
- Ship-to-Shore cargo movement
- Shipboard internal cargo movement, including storage and accessibility.

This document focuses on the Shipboard Internal Cargo Movement (Automated and Integrated Warehouse) area as defined in terms of two principal components:

- *Strike-down* is the process of receiving material from a ship onload point, decomposing from the shipping configuration (when/where necessary), moving the material to the designated stowage location, and securing the material.
- *Strike-up* is the process of locating the required material in its stowage location, decomposing from the shipping configuration (when and where necessary), configuring the material for consumption/shipping, and moving the material to the shipboard location where it will be consumed, used, or transferred off the ship.

The Strike-Up/Strike-Down Roadmap provides an integrated tool to manage and focus S&T funding and potential follow-on Research and Development (R&D) funding for technology and system development. Specifically, the roadmap identifies and prioritizes technology gaps and ***proposes a consensus investment strategy to close the gaps***. The document also provides a common frame of reference to communicate and coordinate the efforts of stakeholders throughout the diverse S&T and R&D communities that include shipyards, elevator vendors, IT vendors, universities, PEOs (Navy, Marine Corps and Army) and the DoD scientific community.

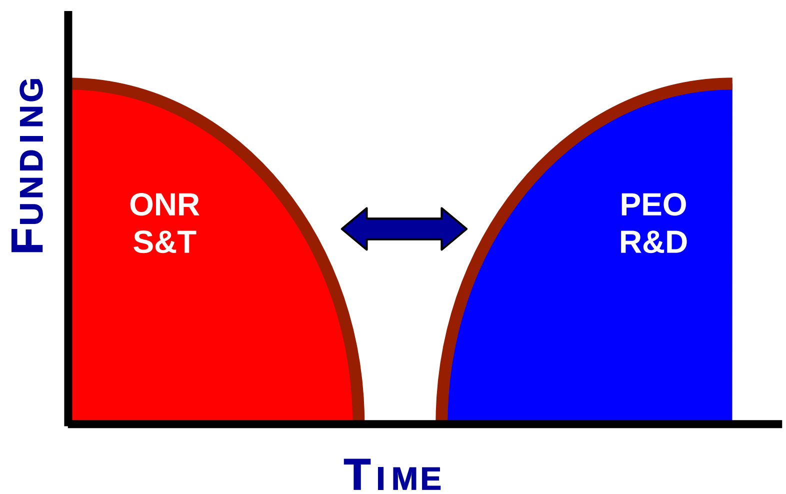
The methodology used in developing the roadmap reveals the essence of its content and structure:

1. Assemble a diverse group of experts representing enterprise-wide perspectives on the issues.
2. Translate the Sea Power 21 Sea Basing strategy into shipboard technology requirements.
3. Identify current technologies (DoD and commercial) with promise to meet the requirements.
4. Prioritize technology gaps that merit DoD funding.
5. Define a time-sequenced, prioritized investment strategy to address the technology gaps.
6. Cross-reference appropriate funding sources and ongoing efforts to highlight the specific S&T investments suited to the FNC sponsor (ONR).

The plan of action must also consider the real world constraints that limit any solution set. The Expeditionary Logistics FNC faces challenges and constraints that are summarized as follows:

- As an integral part of Navy-Marine Corp strategy and a critical need in the Army transformation plan, Sea Basing's broad applicability brings many stakeholders to the decision-making process. This unintended consequence tends to extend decision horizons, when in fact acceleration of technology development in this arena is needed.
- Significant capability enhancement will stem from combinations of technologies that act in concert to provide macro solutions, such that an integrated investment strategy (and monitoring) will provide far greater return than a series of correct, but disconnected technology investments.
- Since the acquisition community is incentivized to sub-optimize solutions to meet the unique cost, schedule and risk aspects of each unique program, well-meaning technology transition concerns in the S&T enterprise have the potential to impede progress in providing multi-platform solutions. This S&T to R&D transition disconnect is depicted by the familiar "Technology Valley of Death" in Figure 1.

Figure 1: Technology Valley of Death



To meet FNC goals within these external constraints, the roadmap exhibits the following attributes:

- Focuses primarily on technologies to deploy on the CVN 21 and MPF(F) ship designs. However, T-AOE(X). LHA(R), DD(X) and LCS are also candidates for application of these technologies.
- Emphasizes solutions that can be affordably deployed on existing ships, such as portable human amplification technologies, in light of the immediacy of fleet needs.
- Favors technologies that enable *manpower reductions* on current and future ship classes that will reduce total ownership costs.
- Differentiates the attractiveness of solutions with applicability across multiple ship designs.
- Balances technology transition probability with the need for appropriate risks in S&T innovation.
- Considers current and planned S&T and R&D, but does not limit analysis or recommendations to continuation or support of past choices.
- Provides a technology portfolio in which diversification mitigates individual investment risks.
- Differentiates the appropriate roles for S&T versus subsequent platform-specific R&D funding.

- Provides an overall plan and tracking tool so that the community can monitor progress and adjust to successes and failures - independent of the funding source of each element.
- Recommends investments in technologies that shipyards who build naval vessels would include in future proposed designs (contingent upon suitability of Navy RFPs).

World events and current national defense policies impose a demand for urgency in expanding the nation's sea basing capabilities. While complete agreement on a solution set that meets all needs and constraints is highly improbable, *the roadmap provides broad consensus on an immediately actionable plan – and agreement that the plan merits immediate action.*

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The Executive Control Board of the National Shipbuilding Research Program would like to recognize the many individuals whose active involvement contributed significantly to the development of this roadmap.

2.1. Workshop Participants

A wide variety of organizational representation was needed to ensure that relevant concerns and issues were fully expressed and understood by other stakeholder organizations. To that end, representatives were invited from various platform sponsors, Navy and Marine Corps engineering and acquisition communities, fleet and force commands, shipbuilding industry, logistics agencies, oversight authorities, as well as commercial warehousing interests. We extend our thanks to the participants for their open discussion and free exchange of ideas during the two-day period, and also to the workshop speakers for providing a baseline understanding of the many aspects of internal cargo movement for those attending the workshop.

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2.2. NSRP Industry Design Review Board (DRB)

This roadmap is the product of many hours of travel, research, meetings, briefings, project reviews and dedicated hard work. A debt of gratitude is owed to the following individuals and their respective parent organizations for the many hours they contributed to this effort.

National Steel and Shipbuilding Co. - Rick Cliffe and Matthew Tedesco
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Northrop Grumman Newport News - Gary Good and Peter Jones
Bath Iron Works Corp. - Steve Nicholson and Peter Mehlhorn
Bender Shipbuilding & Repair Co., Inc. - Pat Cahill

2.3. Project Teams

We acknowledge the cooperation and support of the various SUSD Project Teams. It was through their willing participation, thoughtful insight and candid discussion that the DRB quickly gained a thorough understanding of the internal ship cargo movement technical challenges and potential solutions.

2.4. MPF(F)

Special thanks also to Marty Fink (PMS-325) and Rich Kelly (CSC) for taking the time to travel to Charleston to share with the DRB their comprehensive presentation of strike-up/strike-down technology requirements and Maritime Pre-positioning Force MPF(F) ships in support of the Navy's Sea Basing concept.

2.5. ONR Support Team

Thanks also go to the Strike-Up/Strike-Down team at ONR: Dr. Geoff Main, Rob Evans, Dan Groghan and Dave Lewis, whose technical expertise and many years of experience combined to provide the background and insight necessary for this effort.

2.6. NSRP Support Staff (ATI)

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2.7. Industrial and Corporate Programs, ONR

Special recognition is due Ms. Lynn Torres, ONR's Director of Industrial and Corporate Programs. Her foresight in engaging the NSRP early in the S&T process will help ensure that the technologies developed successfully transition to new platforms. The NSRP appreciates this opportunity to lead the development of technologies which will result in advanced shipboard internal cargo movement systems capable of supporting the Navy's vision for Sea Basing.

3. EXECUTIVE SUMMARY

3.1. The Challenge

The Navy-Marine Corps Sea Basing strategy defined in *Naval Power 21…A Naval Vision,* and in the *Naval Transformation Roadmap, Power and Access…From the Sea* support sustainable global projection of American power by providing advanced command and control; long range, high volume, precise fire support; and vital logistical support from the sea. Sea Basing has many components, including the areas of logistics planning and visibility, ship-to-ship and ship-to-shore cargo movement, and shipboard internal cargo movement that are targeted by Office of Naval Research Science and Technology funding under the Expeditionary Logistics program.

3.1.1. Shipboard Internal Cargo Movement (Strike-Up/Strike-Down)

The Shipboard Internal Cargo Movement challenge is described in terms of complementary phases of cargo movement: strike-up and strike-down. *Strike-down* is the process of receiving material from a ship onload point, decomposing from the shipping configuration (when/where necessary), moving the material to the designated stowage location, and securing the material. *Strike-up* is the process of locating the required material in its stowage location, decomposing from the shipping configuration (when and where necessary), configuring the material for consumption/shipping, and moving the material to the shipboard location where it will be consumed, used, or transferred off the ship.

Cargo movement currently is a series of many manpower/equipment intensive horizontal and vertical moves and handoffs throughout the ship. Shipboard material handling systems must address ways to automate cargo handling operations aboard ship and should include the following technologies:

- Technologies that help move the cargo between ship delivery points and shipboard points of stowage, consumption, or off-load; minimizing both hand-offs and queues in all processes.
- Technologies that provide high-density stowage of cargo loads with positive restraint systems,
- Selective offload technologies to automate cargo holds/magazines and enable individual loads to be called up from stowage.

The primary technical challenge is to handle the existing and future wide variety of naval packaging and weapons.

3.1.2. Shipbuilders as Technology Transition Partners

Overcoming the cargo movement challenges to meet the demands of 21st century Sea Basing requires more than the simple "marinization" of existing commercial systems. It requires a coordinated S&T and follow-on R&D investment to overcome complexities unique to shipboard installations; complexities such as the flex of a hull in high sea states, integration with shipboard power, and cargo load control in high sea states for both handling and stowage, among others. The critical cargo movement advances necessary for Sea Basing require automated and integrated technology solutions which must be designed into new platforms, not merely bolted-on, such that critical tolerances and diagnostics are maintained in higher sea states. Involving shipbuilders initially and throughout the S&T and R&D phases of development of these systems will dramatically increase the probability that newly developed technologies will survive the "Technology Valley of Death" and transition to new ship designs. This will also increase the likelihood that resulting systems will backfit successfully into existing platforms.

Commercial cargo handling systems and current robotics do not meet shipboard requirements and rely on precise tolerances of standardized packaging or precise positioning on an assembly line for repetitive tasks at fixed locations. These systems need to be adapted for shipboard use to overcome challenges not faced by commercially available land-based equipment.

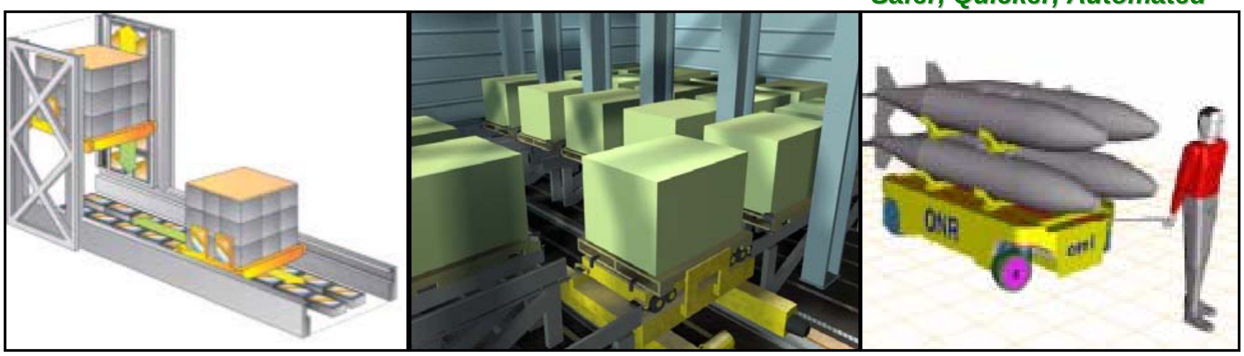
Figure 2: The Challenge and Solution

Shipboard Internal Cargo Movement *today…*

Hazardous, Slow, Manpower Intensive

and tomorrow …

Safer, Quicker, Automated



High Rate Vertical & Horizontal Movement | Automated Warehouse | Compact, Agile Material Mover

3.2. Roadmap Purpose

At the request of the Office of Naval Research (ONR), the National Shipbuilding Research Program Executive Control Board assembled industry experts from shipyards across the nation to coordinate and participate in reviews of existing Strike-Up/Strike-Down investments and develop a technology roadmap to guide future investments. ONR's intent in engaging NSRP for this effort was to identify the consensus view of U.S. shipyards that will eventually transition technologies in the form of future ship designs and construction. In so doing, the probability of FNC investment transition across multiple ship platforms is elevated and the ROI from S&T funds thereby maximized.

The Roadmap provides a specific set of investment recommendations, including priorities, sequence, amounts, and funding source (ONR S&T versus platform R&D). The integrated tool is designed for use in managing and focusing Science and Technology (S&T) funding and potential follow-on Research and Development (R&D) funding for technology and system development. Using it, the community can monitor progress and adjust to successes and failures - independent of the funding source of each element. While the primary target platforms are MPF(F) and CVN 21, other near term ship designs (LHA(R), T-AOE(X), DD(X) and LCS) were also considered in assessing the benefit potential from each technology.

3.3. Approach

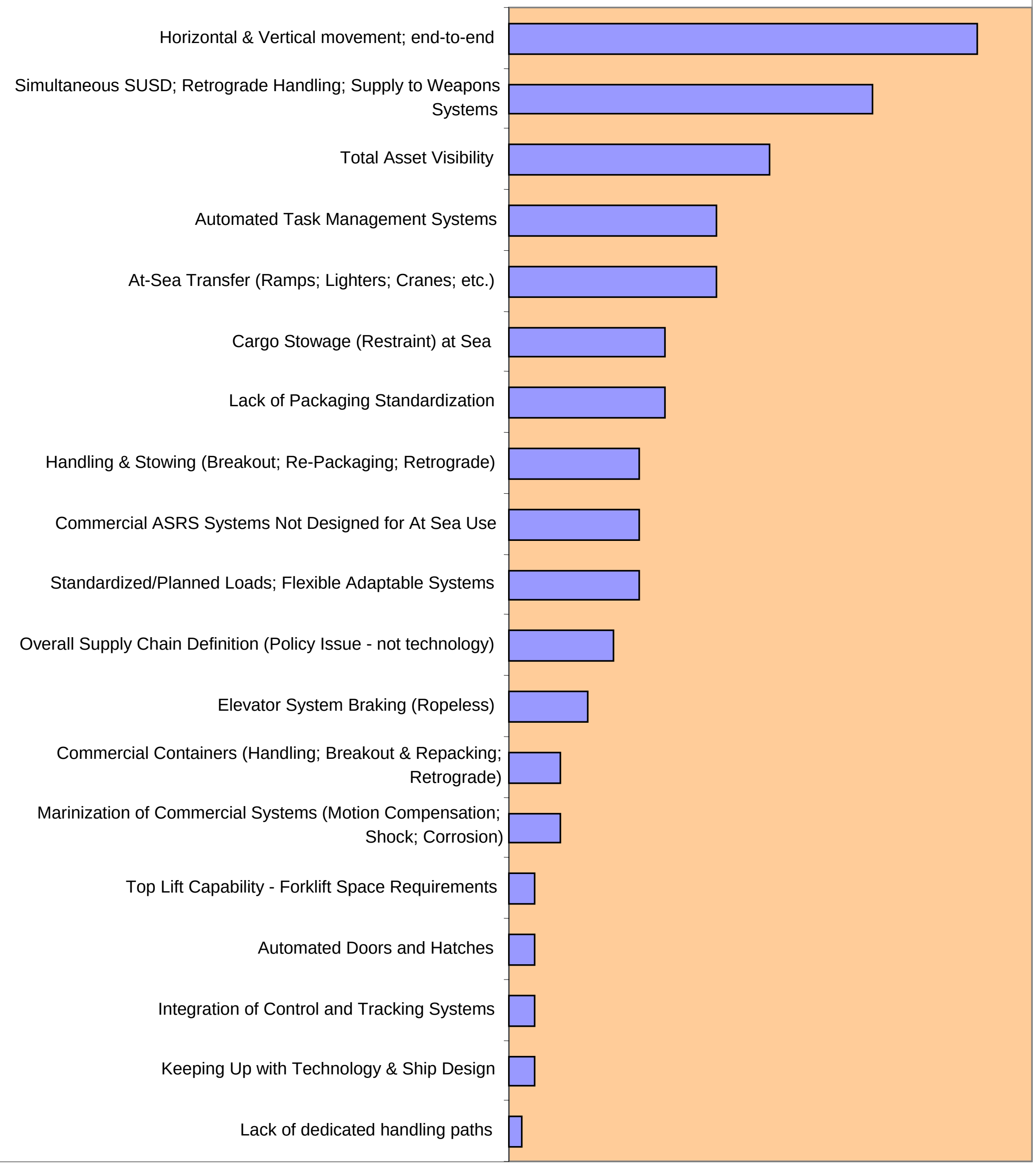
Senior executives from U.S. shipyards assembled a team of experts to lead the process of reviewing requirements and current investments, collecting enterprise-wide corporate knowledge, assessing gaps, and defining a road ahead. A large cross section of industry and government stakeholders assessed strengths, weaknesses, opportunities and challenges for the current shipboard internal cargo movement systems in use today. Participants also identified and prioritized existing process and cultural challenges that limit introduction of new SUSD technologies into the fleet. The stakeholders then prioritized the technology gaps that are impeding the deployment of advanced cargo movement, storage and retrieval systems on Navy ships and mapped them to an efficient, actionable investment portfolio.

Based on the success of NSRP's Strategic Investment Plan for shipbuilding process improvements, the team also considers the SUSD Roadmap as a valuable tool in providing a common frame of reference to communicate and coordinate the efforts of stakeholders throughout the diverse S&T and R&D communities that includes shipyards, elevator vendors, IT vendors, universities, PEOs (Navy, Marine Corps and Army) and the DoD scientific community.

3.4. Gaps and Challenges

The analysis revealed the nineteen specific technology gaps shown in order of relative impact in Figure 3 on the following page. Each of these gaps are explained in Section 5 and subsequently mapped to future investment recommendations in Section 6.

Figure 3: Relative Importance of Technology Gaps (Strike-Up/Strike-Down)



3.5. Results – A Recommended Plan of Action

The Strike-Up/Strike-Down Roadmap identifies and prioritizes technology gaps and ***proposes a consensus investment strategy to close the gaps***. Table 1 lists the enabling capabilities recommended for future funding. For clarity, they are logically grouped into the technology families of High Rate Vertical & Horizontal Movement; Compact, Agile Material Movement; and Automated Warehousing, and Other. A detailed discussion of these recommendations including the associated technology funding currently ongoing is provided in Section 6 of the roadmap.

Table 1: Enabling Capabilities Recommended for Funding

Technology Area and Enabling Capabilities	Period	Funding Source	Comment
High Rate Vertical & Horizontal Movement Technologies (Linear Electric Drive & Rack and Pinion *Note 1*)			
Vertical/horizontal transition	FY04-06	S&T	Vertical to horizontal proof of principle
Removable platform	FY06-07	S&T	Dependent upon outcome of LED vertical to horizontal movement proof of principle
Multiple platforms	FY06-07	S&T	
Compact, Agile Material Mover Technologies (Human Strength Amplification)			
Transporter (HAT-T)*	FY04-06	S&T	Proof of principle transporter
Off-Center-In-Line-Omnidirectional Wheel (OCILOW) concept	FY04-06	S&T	Integral to HAT-T development
Ship motion compensation algorithms	FY04-06	S&T	Considered a basic building block for future shipboard human strength amplification efforts
Ship Motion Simulator	FY04-06	S&T/R&D	Essential for testing HAT-T, OCILOW wheel and ship motion compensation algorithms
Lifting devices (HAT-L & HAT-S, other)*	FY06-07	S&T	S&T follow-on effort
Autonomous operation/navigation	FY06-07	S&T	
Cargo restraint in motion	FY06-07	S&T	
Train mode for transporters	FY05-07	R&D	R&D follow-on effort
Automated Warehouse Technologies (Automated Stowage and Retrieval)			
Automated cargo restraint in motion	FY04-05	S&T	Complete through technology demo
Automated cargo restraint in stowage	FY04-05	S&T	
Adaptability to package size/shape (nesting optimization)	FY04-05	S&T	
Automated container breakout & repackaging	FY05	S&T	This is an MPF(F) specific operational requirement
Other (technology solutions not currently being pursued within ongoing SUSD projects)			
Automated doors and hatches (actuation and control)	FY06	S&T	Provide automatic operation of door and hatches in support of automated cargo movement systems.
Autonomously guided vehicle	TBD pending success or failure of other efforts	S&T	Autonomously operated material handling equipment reduces workload
Selective loading/unloading platform		R&D	Provides increased elevator trunk utilization
Automated task management		R&D	Automates a shipboard warehouse management system

The *Period* column of the table indicates when technology development should commence and the expected duration.

The *Funding Source* column indicates the funding source based on the current level of maturity for that enabling capability. S&T in this column indicates the ExLog FNC as the source of funding. R&D indicates a relatively mature technology that should be funded by the appropriate R&D sponsor when the desired technology readiness level is obtained and the technology development risk is reduced to an acceptable level.

Note 1: High Rate Vertical & Horizontal Movement Technologies - Current focus is on LED technology development that is complementary to the on going NGNN funded ropeless elevator development efforts. Another technology previously funded at the concept level and currently being considered for S&T funding involves "rack and pinion" technology. A funding recommendation is forthcoming pending resolution of technology transition potential in future carriers where this technology will have the biggest impact.

*HAT-T is a 10,000 lbs. capacity transporter; HAT-L is a heavy lift device for large payloads (>500 lbs.) and HAT-S is a sailor strength assist device for handling smaller payloads (<500 lbs.) for operation in more confined spaces.

The product line budget shown in Table 2 is an approximate funding timeline to support S&T and R&D. The term LED is synonymous with the new FNC term Automated Conveyance System (ACS) which includes Linear Electric Drive as well as Rack and Pinion technologies

Table 2: SUSD Investment Plan (in $ Millions)

		FY04	FY05	FY06	FY07	FY08	Totals
High Rate Vertical & Horizontal Movement Technologies	LED I* S&T	0.70	2.00	0.30			3.00
	LED I R&D		0.60	1.20			1.80
	LED II* S&T (Adv)			2.60	1.10		3.70
	LED II R&D (Adv)				2.10	1.10	3.20
Compact, Agile Material Mover Technologies	HAT I S&T	1.90	1.79	0.40			4.09
	HAT I R&D		0.30	1.50	1.80		3.60
	HAT II S&T (Lifters)			2.30	1.90		4.20
	HAT II R&D (Lifters)				1.90	1.20	3.10
Automated Warehouse Technologies	ASRS S&T	1.40	1.77				3.08
	ASRS R&D			11.25	6.2	1.25	18.70
Totals	FY S&T Totals	4.00	5.47	5.60	3.00		18.07
	FY R&D Totals		0.90	13.95	12.0	3.55	30.40
				Program Total			48.47

*An *I* following the project designation (e.g., LED I) denotes a project to be funded immediately whereas *II* denotes a follow-on effort.

Figure 4 is an approximate technology development schedule to support S&T and R&D.

Figure 4: Technology Development Schedule

		FY04	FY05	FY06	FY07	FY08
High Rate Vertical & Horizontal Movement Technologies	LED I S&T	Vertical/horizontal transition				
	LED I R&D		Land-based tests			
	LED II S&T (Adv)		Removable platform Multiple platforms			
	LED II R&D (Adv)			Full-scale demo		
Compact, Agile Material Mover Technologies	HAT I S&T	HAT Transporter / Off-Center-In-Line-Omnidirectional-Wheel concept Ship motion compensation algorithms				
	HAT I R&D		Land/sea-based testing Train mode for transporters			
	HAT II S&T (Lifters)			Autonomous operation/navigation Lifting devices (HAT-L/S) Adapt ASRS cargo restraints		
	HAT II R&D (Lifters)				Land/sea-based testing	
Automated Warehouse Technologies	ASRS S&T	Automated cargo restraint in motion Automated cargo restraint in stowage Adaptability to package size/shape	Automated container breakout and repackaging			
	ASRS R&D		System development	Land/sea-based testing		

4. INTRODUCTION

4.1. Roadmap Overview

The Roadmap is a mix of strategic outlook, business plan, and investment portfolio designed to guide the cost-effective, goal-oriented investment of S&T program funding. It is designed to focus S&T investment dollars on the highest priority technologies that, when coupled with the appropriate R&D funding, can reasonably be expected to transition to advanced shipboard systems capable of meeting the internal cargo movement challenge of Sea Basing (a.k.a. Strike-Up/Strike-Down (SUSD)).

4.2. How the Roadmap is Organized

The complete document is organized into the following sections:

- An **Introduction** provides an overview of the SUSD S&T Roadmap, how it was organized and discusses how it was developed. This section also includes a brief overview of the internal cargo movement challenge.
- The **Mapping Enabling Technologies to Technology Gaps/Challenges** section identifies existing technology gaps to be addressed as a prerequisite to delivering advanced internal shipboard cargo movement systems capable of achieving dramatic increases in cargo throughput rates beyond current capabilities. A list of enabling technologies follows each technology gap description.
- **The Plan** section details the priority order of the enabling technologies to be addressed beginning in FY '04 by funding a limited number of S&T projects specifically addressing those enabling technologies.
- **Appendices** provide more detailed background material such as a description of the ONR SUSD Projects Reviewed, Mapping Technologies to Platforms (Commonality), Culture/Process Challenges, Glossary, SUSD Exit Criteria, TRLs, and various Platform Specific SUSD Visions.

4.3. Roadmap Development

The Roadmap includes elements of a strategic plan and an investment portfolio – integrating technology advancements with a sound business plan. Accordingly, the approach used in developing the Roadmap was strongly oriented towards developing an execution plan to put strategies in motion, rather than an academic exercise in analysis. The recommendations documented in this Roadmap are the **consensus product** of the thoughtful consideration of information collected by members of the Design Review (DRB), a team comprised of individuals with many years of ship design and engineering expertise and experience in cargo movement and weapons handling representing a diverse spectrum of shipyards.

Data was gathered from a number of different sources over a period of many months and included detailed project design reviews of numerous ONR-funded S&T projects and in-depth reviews of other related technology development efforts in their deliberations.

A facilitated two-day workshop was conducted which included representatives from key stakeholder organizations (i.e., the acquisition, resources, requirements and operational communities) to gain a broader perspective of cargo handling issues and to help ensure stakeholder buy-in to the Roadmap. The workshop encouraged open and proactive dialogue among the participants to identify the key technology gaps and associated enabling technologies warranting S&T funding as well as cultural/procedural roadblocks to future S&T transition successes (documented in Appendix C).

The DRB also gave careful consideration to *Naval Power 21…A Naval Vision*, the *Naval Transformation Roadmap*, *Power and Access…From the Sea*, and the final report of the Defense Science Board Task Force on Sea Basing, among others.

4.4. The Internal Cargo Movement Challenge

SUSD capabilities involve internal cargo movement on ships. Strike-down is the process of receiving material from a ship onload point (the CONREP or VERTREP station, wet well, or other loading point), decomposing from the shipping configuration (when/where necessary), moving the material to the designated stowage location, and securing the material. Strike-up is the process of locating the required material in its stowage location, decomposing from the shipping configuration (when/where necessary), configuring the material for consumption/shipping, and moving the material to the shipboard location where it will be consumed, used, or transferred off the ship.

Cargo movement remains a series of many manpower/equipment intensive horizontal and vertical moves and handoffs throughout the ship. Technology solutions to reduce the horizontal and vertical transfer of materials and the transitions between these modes of transport are needed to improve cycle time, throughput rates, and reduce workload. Complexities unique to shipboard installations include the flex of a hull in high sea states, integration with shipboard power, and cargo load control in high sea states for both handling and stowage.

Shipboard material handling systems should address ways to automate cargo handling operations aboard ship and should include the following technologies:

- Technologies that help <u>move the cargo</u> from the delivery point on the ship to the stowage area/magazine, minimizing both hand-offs and queues,
- Technologies that provide <u>high-density stowage</u> of cargo loads with positive restraint systems,
- <u>Selective offload</u> technologies to automate cargo holds/magazines and enable individual loads to be called up from storage.

The primary technical challenge is to handle as much of the wide variety of naval packaging and weapons as possible. Commercial cargo handling systems and current robotics do not meet shipboard requirements. Commercial systems rely on precise tolerances of standardized packaging or precise positioning on an assembly line for repetitive tasks at fixed locations. These systems need to be adapted to shipboard use considering how system tolerances will account for ship flexing in a seaway, static deflection due to load-out, or shock. Ship motions necessitate the restraint and control of loads. These are not considerations for commercially available land-based equipment.

5. Mapping Enabling Technologies to Technology Gaps/Challenges

The overall mission and goal of the Expeditionary Logistics Future Naval Capability (ExLog FNC) program is to identify those mature and evolving logistics technologies that, through focused investment, guidance, and management, can be demonstrated to provide required enabling capabilities. ExLog FNC products must be able to transition to the acquisition community and ultimately new ship designs.

The purpose of involving the U.S. shipbuilding industry via the National Shipbuilding Research Program was to assess existing ONR-funded SUSD projects in the context of this mission, and to provide direction to ensure successful transition of the most promising technologies. Input was solicited from a broad range of stakeholder communities (warfighter, acquisition, shipbuilding, commercial warehousing, R&D, and S&T) to thoroughly identify existing shipboard internal cargo movement technology gaps and challenges.

The ONR-funded SUSD projects (described briefly in Appendix A) were assessed with respect to these gaps and challenges. Additionally, an assessment was made to determine the extent to which the specific projects, or technologies within the projects, are appropriate and sufficiently mature for application to key acquisition programs. Finally, commonality across technologies and platforms was explored to identify and leverage existing synergies. These assessments served to guide development of the Roadmap.

5.1. Identifying and Prioritizing Technology Gaps and Challenges

Technology gaps and challenges were identified during the October 8-9, 2003 ExLog FNC Shipboard Internal Cargo Movement S&T Roadmap Workshop. The purpose of the workshop, and more directly the identification of these gaps and challenges, was to assist in identifying and prioritizing enabling technologies to guide S&T investment. Workshop attendees participated in a benefit analysis exercise to establish a starting point for discussion of what the stakeholders believed was the priority order for overcoming the identified technology gaps and challenges. The group received survey forms and was asked to consider the technology gaps and challenges identified with regard to the impact the gap had on future success. The survey results were tabulated and presented to the entire group for further discussion and refinement.

This prioritization provided additional guidance for identifying S&T focus areas and developing a plan for moving forward with further S&T investment. After the Workshop, the results of the exercise were assessed against perceived platform specific and Sea Basing requirements to demonstrate and validate the relationship between the identified gaps and challenges and future acquisition programs SUSD technology needs. Subsequent to this assessment, areas of commonality across platforms were identified that might suggest the potential for a specific technology to impact multiple ship designs. Finally, specific projects were assessed and plans for proceeding were developed. It should be noted that some of the workshop identified gaps are not addressed by current S&T projects, but may be addressed under ONR BAAs related to other product lines (such as High Capacity Alongside Sea Base Sustainment (HiCASS)).

Table 3 on the following page lists the technology gaps that were identified by the stakeholders, arranged in relative importance to one another.

Table 3: Workshop Identified Gaps & Challenges

	Gap/Challenge to be Addressed	Relative Priority
1	Horizontal and Vertical movement; End-to-End	18%
2	Simultaneous Strike-Up/Down; Retrograde Handling; Supply to Weapons Systems (e.g., elevator systems)	14%
3	Total Asset Visibility-Infrastructure; Interface to Person; Messaging Interface; Bandwidth and Security; Wireless	10%
4	Automated Task Management System (from ordering to retrieval)	8%
5	At-Sea Transfer (Ramps, Lighters, Cranes, etc.) (MPF specific)	8%
6	Cargo Stowage (Restraint) at Sea is Manpower Intensive	6%
7	Lack of Standardization of Packaging	6%
8	Handling & Stowing (Breakout, Re-Packaging, Retrograde, Stow When Received)	5%
9	Conventional ASRS Handling Systems Not Designed for Sea Use	5%
10	Standardized Loads; Planned Loads; Flexible Adaptable Systems	5%
11	Policy – Overall Supply Chain Definition	4%
12	Elevator System Braking (Ropeless)	3%
13	Commercial Containers - Handling; Breakout & Repackaging; Retrograde (MPF(F))	2%
14	Marinization of Commercial Systems - Ship Motion Compensation; Shock; Corrosion	2%
15	Top Lift Capability; Forklift Space Requirements	1
16	Automated Doors & Hatches (that meet requirements for cargo)	1
17	Integration of Control and Tracking Systems	1
18	Keeping Up With Technology & Ship Design; Agility for Future Technology; Design Ships Faster	1
19	Lack of Dedicated Handling Paths	< ½%

Detailed descriptions for each of the gaps listed in the above table are provided in the remainder of this section. In the gap descriptions that follow, enabling technologies are placed in the context of the gaps identified at the workshop.

5.1.1. Horizontal and Vertical Movement; End-to-End (Gap #1)

Gap Characteristics: Captures the need to enable seamless, end-to-end, movement of cargo from Point A to Point B aboard ship with the fewest material handling equipment transfers and the least handling possible.

Discussion: Current platforms require multiple handoffs between cargo movement equipment. These hand-offs are time consuming and manpower/equipment intensive. Today moving cargo from a stowed below deck position to a transfer station on an Underway Replenishment vessel, or from the receiving station to a stowed position below deck, requires many hand-offs as illustrated below.

Consider the following series of events on a CLF-type ship, which involves eight cargo lifts/drops:

Step 1 Cargo is picked up in hold and transferred by forklift truck to a staging area within the hold

Step 2 Cargo is transferred from the hold staging area to an elevator platform by a forklift truck

Step 3 Cargo is removed from the elevator platform by another forklift truck on deck and moved to a staging location on deck

Step 4 Cargo is moved from the on-deck staging location to a transfer station by another forklift truck.

A similar sequence, often more convoluted, occurs in reverse on receiving ships. For instance weapons transferred to a CVN via vertical replenishment (helicopter) are delivered to the stern area of the flight deck and then:

Step 1 Cargo is moved immediately by forklift truck from the drop zone to an aircraft elevator queue

Step 2 Cargo is transferred from the queue by forklift truck onto the aircraft elevator as it becomes available

Step 3 Cargo is lowered to the main deck on the elevator

Step 4 Cargo is moved off the elevator by forklift truck to a temporary queue immediately adjacent to the elevator to expedite elevator off-loading

Step 5 Cargo is moved by forklift truck from the elevator temporary queue to an inspection/staging queue (merged with weapons received via connected replenishment)

Step 6 Cargo is transferred from the staging queue to the respective lower stage weapons elevator queue by forklift truck

Step 7 Cargo is moved by forklift truck from the elevator queue onto the elevator as available

Step 8 Cargo is lowered to the respective magazine on the elevator

Step 9 Cargo is transferred off the elevator by forklift truck to a temporary queue to expedite the release of the elevator

Step 10 Cargo is moved via forklift truck from the temporary queue to the final stowage location.

This process averages eight engagements of the weapons containers/pallets by forklift trucks or similar handling equipment, large work parties at each location, and long periods of time. This gap identifies the need for technology that will eliminate these handoffs of cargo from one material handling device to another to the greatest degree possible.

Enabling technologies to close this gap include:

- Human strength amplification technology. Key functionality involves lifting and precisely maneuvering heavy, bulky cargo and weapons with minimal manpower. Applies to current and future ships, including backfit.
- Omni-directional movement capability. Omni-directional vehicles/platforms used to carry cargo end-to-end without transfer (hand-off) in confined spaces. Applies to current and future ships, including backfit. Key functionality involves precisely maneuvering heavy, bulky cargo and weapons with minimal manpower.
- Autonomous omni-directional vehicles. Same capability described above with reduced manning.
- Ship motion compensation algorithms represent an essential enabling technology for new systems designed to lift or move large loads onboard a ship at sea, whether autonomously or with operator guidance.
- Linear electric drive technologies. In future ships where movement paths can be designed in, mobile platforms using linear electric drive as the prime mover can transport cargo in every direction. Integrating linear electric drive technology into an automated cargo stowage and retrieval system can provide substantial enhancement by eliminating moving parts and reducing maintenance burden.
- Automated cargo stowage and retrieval technologies. In future ships where the system design can be integrated into the ship, these technologies can transport cargo throughout the ship place cargo in stowage location and selectively remove the cargo from stowage.
- Advanced shipboard elevator featuring removable platforms (guided or autonomous). This is essential to meeting cargo throughput rates.
- Improved ballistic hatch opening/closing and dogging mechanisms are essential to meeting CVN cargo throughput rates. May also be applicable to transitioning watertight boundaries on other platforms.

5.1.2. Simultaneous Strike-Up/Strike-Down; Retrograde Handling; Supply to Weapon Systems (Gap #2)

Gap Characteristics: Captures the need to work cargo handling activities in parallel rather than sequentially. Includes challenges associated with handling multiple types of cargo simultaneously. Captures problems associated with handling retrograde materials, which currently wait until other operations are complete.

Discussion: Current means of strike-up/strike-down require sequential operation. Please refer to the examples discussed in paragraph 5.1.1 above.

Enabling technologies to close this gap include:

- Advanced shipboard elevator featuring removable and/or multiple platforms (guided or autonomous). This is essential to meeting cargo throughput rates.
- Multiple platforms operating in the elevator trunk simultaneously would dramatically increase cargo throughput rates.

- Automated cargo stowage and retrieval technologies tailored to enable parallel processing. In future ships where the system design can be integrated into the ship, these technologies can transport cargo throughout the ship in parallel.
- Autonomous omni-directional vehicles enable parallel processing.
- Self (and/or selective) loading/unloading platform enables more effective use of elevator system by reducing waiting periods.
- Improved ballistic hatch opening/closing and dogging mechanisms are essential to meeting CVN cargo throughput rates. May also be applicable to transitioning watertight boundaries on other platforms.
- Linear electric drive technologies. In future ships where movement paths can be designed in, mobile platforms using linear electric drives as the prime mover can transport cargo in every direction. Integrating linear electric drive technology into an automated cargo stowage and retrieval system can provide substantial enhancement by eliminating moving parts and reducing maintenance burden.

5.1.3. Total Asset Visibility: Infrastructure, Interface to Person, Messaging Interface, Bandwidth and Security, Wireless (Gap #3)

Gap Characteristics: Captures the need for material status visibility throughout the supply chain, from CONUS to shuttle and station ships, to receiving ships and to the warfighter.

Discussion: Real time asset management is required to manage high volume, high tempo movement of material. Desired capabilities include automation of supply chain information systems, real time data provided to enterprise resource planning systems and naval tactical command support systems, integration with automated material handing systems, integration with cargo load planning systems, and an open, scaleable standards based architecture. This gap addresses software and hardware issues, including radio frequency identification tags, as well as the over-arching policy, procedure, and infrastructure necessary to make total asset visibility a reality. The focus of this gap is across the entire supply chain, rather than simply intra-ship cargo tracking. This technology gap and challenge is not within the scope of the ONR SUSD tasking, which is focused on intra-ship cargo handling equipment. However, two SUSD projects address parts of this gap. The ASRS project addresses shipboard warehouse management on a limited basis. In addition, the AWE project modeled cargo flow. The T-AKE class (Underway Replenishment Ship) is being provided with a Shipboard Warehouse Management System (SWMS) that integrates inventory management with task management, and is capable of sharing data with legacy Navy inventory management systems.

This technology gap and challenge is currently being explored by the Naval Supply Systems Command Automatic Identification Technology (AIT) project office that supports the broader DoD AIT initiative.

5.1.4. Automated Task Management (from Ordering to Retrieval) (Gap #4)

Gap Characteristics: Captures the need for intra-ship warehouse management systems.

Discussion: This is primarily integration, rather than an S&T technology challenge. Commercial warehouse management systems are readily available and address task management as well as inventory management. The T-AKE class (Underway Replenishment Ship) is being provided with a Shipboard Warehouse Management System (SWMS) that integrates inventory management with task management, utilizing either bar codes or RFID to track material flow. The systems also direct material handling work aboard ship including stowage, breakout, staging, and transfer to stations.

A potential area for improvement and S&T research is related to the development of next-generation systems that incorporate improved algorithms and rule sets for automatically developing cargo load plans.

This a fundamental problem of three-dimensional nesting and optimization subject to constraints, including anticipated orders/receipts, segregation of hazardous cargo, deck strength, hold geometry, etc. An additional potential area for improvement and S&T research is integration of automated task management systems with autonomous material handling equipment.

5.1.5. At-Sea Transfer (Ramps, Lighters, Cranes, etc.) (Gap #5)

Gap Characteristics: Captures the need for new approaches for fuel, cargo, vehicle and personnel transfer in a seaway while on station or underway. It is intended to address both transfer between two large vessels and transfer from a large vessel to a small vessel.

Discussion: ExLog FNC intends to make a major impact on high capacity at-sea transfer through investment in the High Capacity Alongside Sea Base Sustainment (HiCASS) product line. Projects addressing at-sea transfer are outside the scope of this Roadmap. Projects addressing this gap have been solicited by ONR under a HiCASS BAA (04-006).

5.1.6. Cargo Stowage (Restraint) at Sea is Manpower Intensive (Gap #6)

Gap Characteristics: Identifies the need to reduce manpower associated with securing (and un-securing) cargo.

Discussion: Securing and un-securing cargo is currently a manpower intensive, hazardous, and time consuming operation on both station/shuttle ships and receiving ships. Cargo securing systems must accommodate significant ship motion, and must restrain heavy cargo in these conditions. Furthermore, cargo securing systems must be able to accommodate a wide variety of cargo ranging from stores cargo to weapons, in a wide variety of geometric configurations and weights. As a result, existing cargo securing systems are highly flexible, and tend to rely heavily on the expertise of shipboard personnel to execute (examples include dunnage systems that utilize stanchions ("pogo sticks") to restrain cargo from fore-aft and transverse motions). Such stanchions are positioned by personnel against the four faces of cargo (pallets or specialized containers) and locked in place by deck and overhead grid/channel systems. Other examples of traditional cargo securing systems include lashing gear tie-downs and nets. A perceived weakness of current automated stowage and retrieval systems (ASRS) is that current technologies employed in commercial land-based warehouses do not satisfactorily address the issue of cargo securing at sea.

Enabling technologies to close this gap include:

- Automated cargo restraint in motion and stowage to protect cargo and crew members during ship motion in projected sea states.
- Automated stowage and retrieval technologies that enable centralized breakout and repackaging while maintaining cargo restraint.
- Adaptability to package size/shape due to large variety of cargo types in the Navy inventory (an example includes the Standard Payload Interface developed under the NAVSTORS project).

5.1.7. Lack of Standardized Packaging (Gap #7)

Gap Characteristics: Captures the need to address the problem of variability of packaging (methods and sizes) that is perceived to be a stumbling block in the implementation of automation.

Discussion: Variability of package sizes forces shipboard cargo handling, stowage, and securing systems to be highly flexible and adaptable. Flexibility and adaptability are weaknesses of commercially available automated storage and retrieval systems used onshore in warehouse operations. "State of the Shelf" automation in commercial warehouse environments relies heavily on standardization of packaging as an enabler for automation, or relies on very large and open facilities with low stowage density. It is beyond the scope of ONR SUSD tasking to address packaging across the Navy and DoD supply chain. However,

technologies pursued under the ExLog FNC Program must address the challenges imposed by the lack of standardized packaging. This is a critical enabler for the MPF(F) Program, which is currently exploring potential standardization of packaging, including pallets, ISO containers, Reusable Bulk Containers, and Quadcons.

The impact of this gap is mitigated by the same fundamental technologies listed in Gap #6 above.

5.1.8. Handling & Stowing (Breakout, Re-Packaging, Retrograde, Stow When Received) (Gap #8)

Gap Characteristics: Captures the need to address inefficiencies associated with breakout of cargo within a hold, making of mixed pallets (pallets utilizing one or more smaller unit loads from a number of pallets stowed in a hold), re-packaging and stowing of pallets from which material has been removed for the purpose of making mixed pallets, and handling of retrograde and waste associated with cargo handling operations.

Discussion: Fundamentally, this gap addresses difficulties associated with the handling and movement of cargo (loads and partial loads) within holds and the by-products of these operations. This gap includes issues related to the handling operations themselves, and overlaps an earlier gap with respect to activity associated with restraining, or un-restraining cargo.

Enabling technologies to close this gap include:

- Automated stowage and retrieval technologies that enable centralized breakout and repackaging.
- Automated cargo restraint in motion and stowage to protect cargo during ship motion in projected sea states.
- Robotics based on a standard family of actuators to accomplish repetitive handling actions.
- Adaptability to package size/shape due to large variety of cargo types in the Navy inventory (an example includes the Standard Payload Interface developed under the NAVSTORS project).

5.1.9. Conventional ASRS Handling Systems Not Designed for At-Sea Use (Gap #9)

Gap Characteristics: Captures the difficulties associated with integrating commercially available ASRS typical of warehouse operations on shore into a ship. Additionally this gap takes into account the integration of an ASRS with ship structure.

Discussion: This gap is primarily concerned with the challenge of "marinizing" automated stowage and retrieval systems to withstand and address ship motions in high sea states, loads imparted by cargo reacting to these motions, and the restraints required to adequately secure cargo at sea. This gap addresses concerns related to reliability, maintainability, and availability of shipboard equipment. The gap also considers that ASRS in use ashore does not need to be as space efficient as a system in use at sea. An ASRS at sea must be integrated into holds subject to constraints imposed by hullform, damage stability subdivision, and structural design considerations.

Enabling technologies to close this gap include:

- Marinization (shock, ship motion forces, corrosion, structural integration and alignment) of land-based systems.
- Automated Cargo restraint in motion and stowage to protect cargo during ship motion in projected sea states.

5.1.10. Standardized Loads; Planned Loads; Flexible/Adaptable Systems (Gap #10)

Gap Characteristics: Captures challenges posed on shipboard cargo handling operations and overall ship's arrangements as a result of variability of cargoes to be stowed, handled, and delivered.

Discussion: Variability in the quantity and mix of cargo requires flexible and adaptable arrangements and handling systems. In addition to issues related to packaging and handling discussed with respect to previous technology gaps, variable types and quantities of cargo pose challenges related to segregation of hazardous cargo and regulatory body requirements impacting ship arrangements.

Variability of loads to be delivered results in a need for these vessels to be flexible and adaptable, emphasizes selectivity as a key performance characteristic, and requires systems and procedures to address the potential customization of packages for delivery to different end users.

5.1.11. Policy – Overall Supply Chain Definition (Gap #11)

Gap Characteristics: This is a policy-related rather than technology gap which identifies the need for a single organization to take broad responsibility for supply chain policies and procedures across the DoD.

Discussion: Significant improvements in cargo handling efficiency require the intervention of an organization that can act across acquisition programs and platforms. In particular, challenges related to standardization of packaging and manpower reduction will require a broad, joint, and coordinated approach. The Defense Science Board Task Force on Sea Basing identified this challenge in their August 2003 final report, concluding that "a central authority must orchestrate the development of sea basing concepts, systems, and concepts of operations." This conclusion was reinforced during the S&T Roadmap Workshop. While it is outside of the scope of the ONR SUSD tasking to address the development of a central authority, or broad policy, SUSD projects must embody sufficient flexibility and adaptability to adequately address the challenges posed by the current lack of such a central authority or policy. At the time of this writing, DoD announced that it will establish a Joint Sea Basing Requirements Office by March, 2004.

5.1.12. Elevator System Braking (Ropeless) (Gap #12)

Gap Characteristics: Captures a critical need for advanced carriers.

Discussion: Carriers incorporate an offset in vertical paths for weapons movement along with a system of ballistic hatches to enhance ship survivability. In the current fleet, this means that strike-up or strike-down must occur in a series of steps, with transitions from one elevator shaft to another to traverse the entire distance. A "ropeless" elevator that can transition a ballistic hatch and operate below a closed hatch would reduce these hand-offs. Development of an adequate braking mechanism is a technical challenge associated with the technologies examined to date (linear electric drive and mechanical advanced weapons elevator concepts). While an effective braking mechanism is fundamental to shipboard elevators, ropeless elevator concepts make braking particularly challenging.

Enabling technologies to close this gap include:

- Parking brake to eliminate the need for power when elevator platform remains stationary for loading, unloading, or maintenance.
- An emergency brake to deal with loss of power.

5.1.13. Commercial Containers: Handling; Breakout & Re-Packaging; Retrograde (Gap #13)

Gap Characteristics: This MPF(F) specific gap captures challenges associated with handling commercial ISO containers as a central part of the Sea Basing concept of operations. These challenges include transfer of containers from shuttle ships (potentially commercial containerships) to the future MPF(F) ships in high sea states, handling and breakout of containers aboard ship, selective loading and unloading of containers at sea, and sending empty containers back to shuttle ships.

Discussion: Technical issues related to transfer of containers at sea are not within the scope of the ONR SUSD tasking, and are instead part of the HiCASS product line. However, issues related to intra-ship handling of containers, and handling of cargo stowed in containers, is within the scope of the ONR SUSD tasking.

Enabling technologies to close this gap include:

- Automated stowage and retrieval system for large containers. This applies specifically to MPF(F). It is not addressed specifically by the current SUSD projects but fits a future vision of ASRS. In this regard, Military Sealift Command (MSC) has been working with Maersk on an Afloat Forward Staging Base concept based on a converted S-class container ship which will offer selective offload capabilities.
- Robotics based on a standard family of actuators to accomplish repetitive breakout actions.
- Human amplification technologies to facilitate breakout of cargo from containers.

5.1.14. Marinization of Commercial Systems: Ship Motion Compensation; Shock; Corrosion (Gap #14)

Gap Characteristics: Captures the challenges associated with ensuring that cargo handling technologies assessed under the ONR SUSD tasking adequately addresses the requirements for operation at sea.

Discussion: Most of the technologies being examined under the ONR SUSD tasking are derived in some way from technologies used ashore. Therefore this is a fundamental concern that applies to SUSD projects. Some SUSD projects are primarily focused on addressing this challenge.

Enabling technologies to close this gap include:

- Ship motion compensation algorithms represent an essential enabling technology for new systems designed to lift or move large loads onboard a ship at sea, whether autonomously or with operator guidance.

5.1.15. Top Lift Capability; Forklift Space Requirements (Gap #15)

Gap Characteristics: Identifies the need for overhead cargo handling equipment that can access and lift cargo to a staging area in a hold or to transfer to other cargo handling equipment for further movement.

Discussion: In confined spaces, top lift capable equipment could be used in lieu of forklifts to place cargo on an ASRS carriage or other equipment. There also may be ASRS systems that access cargo from above as alternatives to ASRS systems that use deck mounted carriages.

If there is a need to handle and move containers longitudinally in a fixed path through the ship, overhead lifting systems may be preferable over large, heavy portable container handlers. If there are vessel arrangements where pallets or quadcons need to be lifted below decks from a pallet or container hold, an overhead cargo handling system would be needed.

At vessel loading or unloading stations, cargo operations may require the capability to lift pallets or containers to place on other handling equipment. Lifting pallets from above requires personnel to rig slings and spreaders. There is a need to reduce this manpower for arranging pallet slings or attaching lifting gear to cargo.

Connected replenishment utilizes a top-lift capability. If similar means are used to move cargo and weapons internal to the ship, the challenges associated with tracks in the deck (i.e., restricting deck area use) and deck point loading of omni-directional vehicles are mitigated.

Enabling technologies to close this gap include:

- Current projects are not specifically addressing this issue; however, some automated stowage and retrieval systems do include top lift capability, e.g. the Standard Payload Interface of the NAVSTORS project.
- Electric/electric-hybrid actuators could also apply to this gap.

5.1.16. Automated Doors and Hatches (That Meet Requirements for Cargo) (Gap #16)

Gap Characteristics: Captures the need to safely and effectively move cargo from compartment to compartment through water tight boundaries, damage control zones, environmental enclosures, etc. Also captures a critical need of the CVN-21 Program. Carriers incorporate a system of ballistic hatches between deck and magazines to enhance ship survivability. A "ropeless" elevator is being pursued that can transition a ballistic hatch to reduce these hand-offs. However, improvement of the ballistic hatch opening/closing and dogging mechanism is essential to meeting CVN cargo throughput rates.

Discussion: Standard electric actuators can be integrated with doors and hatches to provide automatic operation in support of cargo movement. The actuators can be integrated with the shipboard warehouse management system (SWMS) and/or autonomous vehicles to coordinate opening/closing with vehicle movements. Carriers incorporate a system of ballistic hatches between deck and magazines to enhance ship survivability. A “ropeless” elevator is being pursued that can transition a ballistic hatch to reduce these hand-offs. However, improvement of the ballistic hatch opening/closing and dogging mechanism is essential to meeting CVN cargo throughput rates.

Enabling technologies to close this gap include:

- Enhanced actuating systems could be used to automate existing or new design doors and hatches.
- Automated operation would require control system integration which is likely not S&T but should be applied during R&D or acquisition.

5.1.17. Integration of Control and Tracking Systems (Gap #17)

Gap Characteristics: Captures the need for integrated and coordinated information systems.

Discussion: This gap addresses the need to integrate the solutions to two previous gaps (Total Asset Visibility - Gap #3, and an Automated Task Management System – Gap #5).

5.1.18. Keeping Up With Technology and Ship Design; Agility for Future Technology; Design Ships Faster (Gap #18)

Gap Characteristics: Identifies technology insertion challenges faced by the acquisition community.

Discussion: This gap addresses widespread perceptions that current approaches to ship design and acquisition do not adequately address technology insertion or the speed of technology development. Constraints in the design process force early decisions, which combined with lengthy design cycles, tend to prohibit integration of state of the art systems and equipment at the time of ship delivery. This gap, which primarily addresses policy rather than the technology itself, is outside the scope of the ONR SUSD tasking. However, increased communications flow and flexible technology transition agreements between technology providers and acquisition programs could help mitigate the impact of this gap.

5.1.19. Lack of Dedicated Handling Paths (Gap #19)

Gap Characteristics: Captures the fact that cargo handling efficiency is a secondary consideration on most vessels - which lack area and volume dedicated to cargo handling routes.

Discussion: Cargo vessels such as T-AKE have been arranged with dedicated cargo handling paths to maximize cargo handling efficiency. However, the majority of naval vessels, including carriers, have

been arranged with their primary mission as the driver. As a result, cargo handling routes can be inefficient, and suffer from bottlenecks and congestion. With area and volume at a premium, designers face a substantial tradeoff between cargo handling and other shipboard operations.

Enabling technologies to close this gap include:

- Autonomously guided vehicles optimize paths and have capability to maneuver around obstacles.
- Omni-directional transporter enables maneuvering in tight spaces.
- Automated doors and hatches (actuation and control) linked to overall task management can streamline the overall operation.

5.2. Technology Gaps Summary

Table 4 summarizes the foregoing technology-related gaps and enabling technologies and provides a cross-reference to the projects described in Appendix A.

Table 4: Mapping Technology Gaps to Enabling Technologies to Past/Recent Projects

S&T Technology Gap	Enabling Technology(ies) required to close gap	HAT	LEDT	ASRS	AWE	NAVSTORS	ODV	Project TBD
Horizontal and Vertical Movement; End-to-End (Gap #1)	Human strength amplification	√						
	Omni-directional vehicular movement	√		√		√	√	
	Ship motion compensation algorithms	√						
	Linear electric drive as a prime mover		√					
	Automated cargo stowage and retrieval			√		√		
	Advanced shipboard elevator featuring removable platforms		√		√			
	Advanced ballistic hatch opening, closing and dogging mechanisms				√			√
Simultaneous Strike-Up/Down; Retrograde Handling; Supply to Weapon Systems (Gap #2)	Advanced shipboard elevator featuring removable platforms		√		√			
	Multiple platforms operating in trunk simultaneously		√					
	Automated cargo stowage and retrieval			√		√		
	Human strength amplification transporters operated in “trains”	√						
	Autonomous omni-directional vehicles						√	
	Advanced ballistic hatch opening. closing and dogging mechanisms				√			√
	Self (and/or selective) loading/unloading platform							√
	Linear electric drive as a prime mover		√					
Cargo Stowage (Restraint) at Sea is Manpower Intensive (Gap #6)	Automated cargo restraints in motion and stowage			√		√		
	Automated cargo stowage and retrieval			√				
	Adaptability to package size/shape					√		
Lack of Standardized Packaging (Gap #7)	Adaptability to package size/shape			√		√		
Handling & Stowing (Breakout, Re-Packaging, Retrograde, Stow When Received) (Gap #8)	Automated cargo stowage and retrieval			√		√		
	Automated cargo restraints in motion and stowage			√		√		
	Robotics based on a standard family of actuators				√			
	Adaptability to package size/shape					√		
Conventional ASRS Handling Systems Not Designed for At-Sea Use (Gap #9)	Automated cargo restraints in motion and stowage			√		√		
	Marinization (shock, ship motion forces, corrosion, etc)							√

S&T Technology Gap	Enabling Technology(ies) required to close gap	HAT	LEDT	ASRS	AWE	NAVSTORS	ODV	Project TBD
Elevator System Braking (Ropeless) (Gap #12)	Parking brake		√		√			
	Emergency brake		√		√			
Commercial Containers: Handling, Breakout & Re-Packaging; Retrograde (Gap #13)	Automated stowage and retrieval of large containers			√				
	Human strength amplification	√						
	Robotics based on a standard family of actuators				√			
Marinization: Ship Motion Compensation; Shock; Corrosion (Gap #14)	Ship motion compensation algorithms	√						
	Convert commercial technology to shipboard environment			√			√	
Top Lift Capability; Forklift Space Requirements (#15)	Not addressed by the existing technology projects							√
Automated Doors and Hatches (That Meet Requirements for Cargo) (Gap #16)	Advanced ballistic hatch opening. closing & dogging mechanisms				√			√
	Electric/electric/hybrid actuators		√		√			
Lack of Dedicated Handling Paths (Gap #19)	Automated doors and hatches							√
	Omni-directional vehicular movement	√		√		√	√	
	Autonomous vehicle navigation and control						√	

5.3. Culture/Process Challenges

Throughout the development of this document it was noted that transition of new technologies to Navy platforms was being inhibited by factors not related to technology. A number of cultural and procedural influences were identified which were inhibiting successful technology development and transition. Stakeholders participating in the Roadmap Workshop were asked to identify and define the key culture and process challenges impeding new technology transitions. The various challenges identified at the workshop are grouped into the five general categories listed in Table 5. See Appendix C for discussion of these culture and process challenges.

Table 5: Stakeholder Identified Culture/Process Challenges and Key Issues

Challenges	*Key Issues*
Risk Aversion	Risk exists at many levels and can impede new technology development and transition.
Change Aversion	A culture resistant to change can have negative consequences for technology transition.
Centralized Technology/ Innovation Authority	A centralized technology/innovation organization is needed to provide a clear vision and champion projects through the approval process.
Process	The technology innovation process needs to be streamlined.
Funding	Consistent funding for both S&T and R&D is needed to speed technology development and transition.

6. THE PLAN

To guide development of the Roadmap certain assessments were made. The current SUSD projects were assessed with respect to gaps, as described in the previous section. In addition, the extent to which specific projects, or technologies within projects, are necessary and sufficiently mature for application to key acquisition programs was considered. Finally, commonality across technologies and platforms was explored to identify and leverage existing synergies.

6.1. The Transition Imperative

Platform requirements have played a critical role in steering development of this roadmap as did ONR's mandate to determine the applicability, viability, and maturity of the S&T efforts that will achieve the appropriate Technology Readiness Level (TRL) for R&D transition into new shipbuilding acquisition programs. TRL maturity levels for each of the SUSD exit criteria are listed in Appendix E. TRL definitions are provided in Appendix F. This roadmap will help ensure that the scarce ExLog FNC funding available for S&T projects supporting shipboard internal cargo movement for future Navy ships is directed at technologies that have the highest probability of transitioning into new platforms. The primary target platforms include CVN 21 and MPF(F) (or more broadly, Sea Basing as a concept of operations). However, T-AOE(X), LHA(R), DD(X), and LCS are also considered candidates for new technology transitions. Of these, T-AOE(X) and LHA(R) are of particular interest as they are required to support ("connect") to the primary target platforms and operate within the context of the Sea Basing concept of operations. The direct transition of these S&T efforts to platform specific R&D programs is critical to this overall technology development effort. Moreover, it's imperative that the Navy integrate the development of afloat logistics systems across ship programs, an effort that's integral to the Naval Operational Logistics IPT (OpLog IPT) mission. An optimized amalgamation of the ONR S&T, platform specific R&D, and OpLog IPT R&D efforts/funding must be the end game.

6.2. Commonality

The primary mandate of the Roadmap is to identify promising S&T that could be tied directly to future shipbuilding acquisition programs, thereby ensuring a high probability of transition. It was also important to identify areas of commonality between platforms that may reinforce conclusions regarding investment decisions. Applicability across platforms provides additional incentive and justification for investment and therefore these areas of commonality influence the recommended plan of action that follows. The *Platform Applicability* column of Table 6 is included to illustrate this commonality across platforms.

- *E = Essential* means that this technology is required for the particular platform to complete its mission.
- *B = Beneficial* means that the technology will help the particular platform improve cycle-time, reduce manning or both but it is not an essential requirement.
- *A = Acceptable* means that this technology can be applied on the platform in order to support standardization but the technology in itself will not provide substantive cycle-time or reduced manning benefit.
- *n/a = Not applicable* means that this technology cannot or should not be considered for application to this particular platform.

6.3. Moving Forward

Significant SUSD advancements will only be achieved through a combination of various technologies that interface to offer a global solution. The integration of technologies may provide enhanced benefits over the individual technologies. Where parts of one proposal have synergy with a different project, teams should consider bringing them together.

The NSRP recommendations (listed in priority order) for moving forward are summarized in the following table and associated descriptions.

Table 6: Funding Recommendation Summary

Legend: E = Essential, B = Beneficial, A = Applicable, n/a = Not Applicable

Other refers to technology solutions that the DRB recognizes as essential but is currently being funded or pursued by other sources or is complete. **Essential Baseline Technology** indicates an enabler of higher level technology objectives that is not specific to a particular platform, but is an essential enabler for a technology independent of a particular platform (i.e., ship motion compensation is an essential building block of human amplification technology).

				Platform Applicability						
Technology Area and Enabling Capabilities	**Period**	**Source**	**Comment**	CVN 21	MPF(F)	T-AOE(X)	LHA(R)	CLF Backfit	CVN/LHA Backfit	Combatant or Amphib
High Rate Vertical & Horizontal Movement Technologies (Linear Electric Drive and Rack & Pinion)										
Vertical/horizontal transition	FY04-06	S&T	Vertical to horizontal proof of principle	B	B	B	B	n/a	n/a	B
Removable platform	FY06-07	S&T	Dependent upon outcome of LED vertical to horizontal movement proof of principle	E	B	B	B	n/a	n/a	B
Multiple platforms	FY06-07	S&T		E	B	B	B	n/a	n/a	B
Payload capacity	Other		These essential technologies are currently being funded separately as part of the ongoing NGNN AWE design competition	E	E	E	E	E	E	E
Braking	Other			Essential Baseline Technology						
Positioning and control	Other			E	E	E	E	E	E	E
Ballistic hatch transition	Other			E	n/a	n/a	n/a	n/a	n/a	n/a
Weight, volume, and power impact (high performance materials)	Other			Essential Baseline Technology						
Compact, Agile Material Mover Technologies (Human strength amplification)										
Transporter (HAT-T)	FY04-06	S&T	Proof of principle transporter	B	B	B	B	B	B	B
Off-Center-In-Line-Omnidirectional Wheel (OCILOW) concept	FY04-06	S&T	Integral to HAT-T development	B	B	B	B	B	B	B
Ship motion compensation algorithms	FY04-06	S&T	Considered a basic building block for future shipboard human strength amplification efforts	Essential Baseline Technology						
Ship Motion Simulator	FY04-06	S&T	Essential for HAT-T, OCILOW wheel and ship motion compensation algorithms	Essential Baseline Technology						
Lifting devices (HAT-L & HAT-S, other)*	FY06-07	S&T	S&T follow-on effort	B	B	B	B	B	B	B
Autonomous operation/navigation	FY06-07	S&T		B	B	B	B	B	B	B
Cargo restraint in motion	FY06-07	S&T		B	E	B	B	B	n/a	B
Train mode for transporters	FY06-07	R&D	R&D follow-on effort	B	B	B	B	B	B	B

Table 6: Funding Recommendation Summary

Legend: E = Essential, B = Beneficial, A = Applicable, n/a = Not Applicable

Other refers to technology solutions that the DRB recognizes as essential but is currently being funded or pursued by other sources or is complete. **Essential Baseline Technology** indicates an enabler of higher level technology objectives that is not specific to a particular platform, but is an essential enabler for a technology independent of a particular platform (i.e., ship motion compensation is an essential building block of human amplification technology).

				Platform Applicability						
Technology Area and Enabling Capabilities	**Period**	**Source**	**Comment**	CVN 21	MPF(F)	T-AOE(X)	LHA(R)	CLF Backfit	CVN/LHA Backfit	Combatant or Amphib
Automated Warehouse Technology (Automated Stowage and Retrieval)										
Automated cargo restraint in motion	FY04-05	S&T	Complete through S&T technology demo	B	E	B	B	B	n/a	B
Automated cargo restraint in stowage	FY04-05	S&T		B	E	B	B	B	n/a	B
Adaptability to package size/shape (nesting optimization)	FY04-05	S&T		B	E	B	B	B	n/a	B
Automated container breakout and repackaging	FY05	S&T	This is an MPF(F) specific operational requirement	n/a	E	n/a	n/a	n/a	n/a	n/a
Standard payload interface (NAVSTORS)	Other		Funded under SBIR Phase 2	B	B	B	B	n/a	n/a	B
Marinization (e.g., shock, ship motion forces, corrosion, and structural integration and alignment)	Other		These essential considerations should be funded as part of any S&T technology development	Essential Baseline Technology						
Stowage density	Other		These are critical considerations for shipboard automated stowage and retrieval systems being developed	B	E	E	B	E	n/a	B
Selective offload	Other			B	E	E	B	E	n/a	B
Other (technology solutions not currently being pursued within established SUSD projects)										
Automated doors and hatches (actuation and control)	FY06	S&T	Provide automatic operation of door and hatches in support of cargo movement	E	B	B	B	n/a	n/a	B
Autonomously guided vehicle (AGV)	TBD pending success or failure of other efforts		S&T – Autonomously operated MHE reduces workload	B	B	B	B	n/a	n/a	A
Selective loading/unloading platform			R&D – Provides increased elevator trunk utilization	B	B	B	B	B	B	B
Automated task management			R&D – Automates a shipboard warehouse management system (SWMS)	E	E	E	E	E	E	E
High power density electric/electric-hybrid actuator	Other		Currently being funded by the FNC, SBIR and ONR Electric Ship project.	Platform Independent – An Enabler						

6.4. Linear Electric Drive (LED)

The LED system utilizes linear synchronous motors as the prime mover, providing motive forces with a stationary drive system. It is the underlying technology in the advanced weapons elevator (ropeless) concept currently being developed for CVN 21 by Northrop Grumman Newport News (NGNN). While the primary purpose of LED technology in the NGNN effort is vertical movement of the platform within the shaft, LED technology could be exploited to further improve shipboard internal cargo movement by developing technologies that would enable the elevator platform to automatically transition from vertical movement to horizontal movement and exit the shaft. This transition capability, properly integrated into the ship design, could provide hands-off end-to-end cargo movement and thereby significantly increase cargo throughput.

In addition to the basic elevator technologies (i.e., payload capacity braking, ballistic hatch transition, etc.) being funded by the NGNN effort, the DRB recommends concurrent development of the following three additional LED technologies for application in future ship designs of other platforms, including MPF(F).

> **Vertical to horizontal transition (FY04-06/S&T):** Pursue the design development of LED S&T to accomplish the vertical to horizontal transition of internal cargo including a proof of principle demo by the technology provider. The technology and design detail for making the transition from vertical to horizontal movement is fundamental to the overall stator column design. This transition is not required for CVN 21 and will probably not be accomplished without ONR support. This is a basic technology that significantly enhances the potential for expanded end-to-end cargo movement without cargo hand-offs.

> **Removable platform (FY04-06/S&T):** A significant operational feature of the vertical to horizontal transition is the potential for an elevator platform to exit the elevator trunk at every level and move horizontally along a predetermined track. This technology would enable movement to a designated loading/unloading area outside the trunk and thereby eliminate one cargo hand-off. The platform could carry the cargo to the end-point (CONREP/VERTREP station or stowage location) if properly integrated into the ship design. The S&T component in this area is the ability for the platform, stator system, and guide rail assemblies to fully disengage from the trunk.

> **Multiple platforms (FY04-06/S&T):** Another potential operational feature is the possibility of multiple platform operation within a trunk, either simultaneously or independently when removable platforms are out of the trunk. This improves trunk usage and could significantly enhance overall throughput. In addition to the removable platform enabling technology mentioned above, the S&T component of this area is the development of controls and power management system necessary to operate multiple platforms simultaneously.

The Roadmap assumes that the design issues considered fundamental to the development of advanced weapons elevators will be adequately addressed in the NGNN elevator effort. The following comments are intended to highlight specific challenges as key to successful implementation of LED technology within that effort.

> **Payload capacity:** Must demonstrate the ability to lift, lower and hover with the full cargo load under specified operational conditions for roll, pitch, and heave. Hovering is likely the most challenging feature because it requires exacting motion control, maximizes power consumption and generates heat.

Braking: Two separate types of brakes must be developed: parking brakes to hold the elevator platform at a specific level so that hovering power is not demanded for long periods and emergency brakes that can stop and hold the platform in the event of a power loss.

Positioning and control: The elevator platform must be controlled to a high degree of precision so that it lands at the deck levels within operational tolerances. Control difficulty would increase because there are four (4) separate linear motors to control simultaneously. It is also necessary to consider failure conditions where a single linear motor fails and the full load must be absorbed by the remaining three (3).

Ballistic hatch transition: The LEDT team's initial direction was to design for a 20 inch opening (gap) at the ballistic hatch; however, in reviewing the hatch design, the DRB found that this doesn't address the actual interface problem. Designing the linear motors for this size gap drives predicted power requirements significantly beyond what would actually be required if the gap was eliminated or minimized. The LED teams currently developing this technology for CVN 21 should interface with NGNN to develop a detailed design consistent with the design and operation of the ballistic hatch.

Weight, volume and power impact: It appears that the stator columns required by LEDT will add significant overall weight and that the linear synchronous motors will be less efficient than the current rotary motors used in Navy standard (rope) elevators. It is essential that total ship weight, volume, and power impacts be considered during LED technology development. The DRB also recommends that a formal weight control/reduction program be implemented.

6.5. Human Strength Amplification

As one of the ten original SUSD concept phase projects, HAT focused on advancing specific enabling technologies needed to achieve substantial improvements in the human interface to a broad range of ship-board material handling challenges. Though not originally selected for subsequent ONR funding, the roadmap analysis revealed that it is essential to the overall SUSD program objectives. By fully developing the specific technology components addressed in this project and integrating them in various combinations with previously developed HAT components or other related technologies, HAT will offer efficient alternatives to a wide variety of labor intensive, time consuming, and cumbersome material handling tasks.

Transporter (HAT-T) (FY04-06/S&T): One of the three primary project objectives is to develop a proof of principle powered transporter which will enable a single individual to precisely and effortlessly move payloads of up to 10,000 pounds throughout a ship in the full range of operational environmental conditions. HAT–T is a readily scalable technology. A family of transporters with various capacities from a few hundred to several thousand pounds may be necessary to effectively move internal cargo on various ship classes. The initial version of HAT-T will be manually controlled.

Off-Center-In-Line-Omnidirectional-Wheel (OCILOW) (FY04-06/S&T): This wheel design including powering and control is integral to the HAT-T outlined above and must be developed concurrently. The OCILOW achieves holonomic mobility using conventional wheels for more positive control and offers a wider range of capability than other omni wheel designs.

Ship Motion Compensation Force Control System (FY04-06/S&T): This is the key control component of the HAT project. It is a set of sophisticated control algorithms which reduce or eliminate the effects of low frequency dynamic loading caused by wave induced ship movement

while lifting, moving, or otherwise manipulating heavy payloads. These algorithms were developed during the concept development phase of this project but must be validated and tested before integration into other HAT-based equipment. Control algorithms have direct applicability to other systems.

Ship Motion Simulator (FY04-06/S&T+R&D): Though not a technology component of HAT directly, a ship motion simulator is required to validate the SMCFCS discussed above and the specific equipment on which these control algorithms are employed. There are no simulators currently available which have sufficient fidelity to perform the required tests.

Lifting devices (FY06-07/S&T): The development of a heavy lifter (HAT-L) for large payloads and a sailor strength assist (HAT-S) device for handling small payloads or operation in more confined spaces were the other two primary objectives of the original HAT project. Specific application for these lifting/manipulating machines and their related end effectors/payload interface devices may be platform dependent but the resulting effects will be the same: reduced workload, reduced fatigue of remaining personnel, enhanced safety, and improved output/throughput.

Autonomous navigation (FY06-07/S&T): One of the specific applications for the HAT-T systems is for mass movement of cargo during resupply operations. In these cases, when moving material across or through large expanses of relatively open deck areas, the direct human interface with individual transporters would not be effective utilization of available manpower. The ability of transporters to individually or collaboratively develop an optimized path for movement from one location on a deck to another while safely avoiding both stationary and moving obstacles would be a major benefit. Although not an objective of the original HAT project, technologies currently in use or being developed under other programs could be integrated into the HAT-T control system to provide this additional flexibility. This would enable the HAT-T to have dual control modes: 1) a HAT interface for positive, precise control in critical movement areas and; 2) autonomous/swarm control for movement in open deck areas. Dual controls could be effectively used for both strike-down and strike-up.

Cargo restraint in motion (FY06-07/S&T): The need to provide positive restraint for material during the movement on HAT-T or other transporting/moving equipment must be thoroughly assessed. An automated integrated restraint system must be developed to be utilized in the specific cases when/where positive restraint is required. Cargo restraint in this project can possibly benefit from the cargo restraint solutions developed for ASRS.

Train mode for transporters (FY05-07/R&D): This is a variation of control modes discussed above that would provide positive control over the simultaneous movement of a number of transporters by a single individual. The lead transporter would be under positive control of the sailor through the HAT-T controller and the trailing transporters could either be configured with a mechanical interface one to the other or by a "virtual" coupling through collaborative control algorithms.

Specific applications for various combinations of HAT components integrated in future R&D efforts could be:

- End-to-end transporters which move cargo from VERTREP drop zones to their respective storage location without additional intermediate interface during strike-down. These could also be reconfigured to support specific support applications for end-to-end movement of material during strike-up. Transporters could have dual movement control interfaces as discussed above.

- Automated picking stations or material/weapon breakout equipment.
- Automated component mating/integration, weapons assembly equipment, weapons loading equipment, etc.
- For open deck configurations, provide a highly optimized automated storage and retrieval system offering unlimited flexibility to achieve optimum selectivity for retrieval, maximum storage density, or some variable combination thereof.
- Other applications where human assisted lifting/moving capabilities would enhance system effectiveness, reduce workload/manpower, and enhance safety.

6.6. Automated Stowage and Retrieval

SUSD Investments should pursue specific technologies that will lead to a shipboard demonstration in the 2005-2006 time frame in order to support MPF(F). Its intent is to take an existing commercial ASRS system and do the conversion necessary to adapt it to the shipboard environment. The project will build on the Phase I ASRS feasibility project already accomplished by the General Dynamics Armament and Technical Products and Siemens Dematic team. This phase is expected to resolve technology issues necessary to support a full scale shipboard demonstration in the next phase. Additional technical issues that arise during this phase must also be considered before moving to the full scale demonstration project. Specific technologies that need to be addressed, and which are supported by the recommended demo project, include:

Automated cargo restraint in motion (FY04-05/S&T): The need is to provide a simple but effective means of constraining the cargo to the platform during cargo movements. The driving design requirement is roll, pitch and heave in the specified operational sea state. The restraint system must also provide a "lock down" capability that can be activated if ship motions exceed the operational specification. This lock down capability should ensure safety of both the cargo and the system.

Automated cargo restraint in stowage (FY04-05/S&T): When in the stowed location, cargo needs to be restrained against movement in specified "survival" sea state conditions. The restraint system should be passive or simple and automated, if possible. It should be automatically activated as soon as the cargo is deposited in the stowage location by the shuttle/satellite.

Adaptability to package size/shape (nesting optimization)(FY04-05/S&T): At a minimum the system should demonstrate the capability to handle RBCs as well as standard 44 x 48 pallets fully loaded with FIULs (Fleet Issued Unit Loads). The adaptation capability should be able to adjust to the size/shape of the cargo and constrain it as described above. A positive means of securing material to open pallets that's commercially viable for NAVSUP, DLA, Primary Navy Vendors, etc. must be defined for fleet wide application.

Automated Container Breakout and Repackaging (FY-05/S&T): This is an MPF(F)-specific operational requirement. It is assumed that the bulk of cargo will be transported to the MPF(F) in 20 Foot ISO containers. The containers must be unloaded and returned as retrograde. The cargo will likely be re-packaged into Quadcons, RBCs or pallets for stowage and delivery to the customers. HAT and standard electrical actuator technologies can be integrated with ASRS technology to assist ship’s personnel in this endeavor. This automation will be tailored to the specific applications and optimized for repetitive operations.

Marinization (Other): Converting a commercial ASRS to shipboard implementation requires "marinization" of certain features, some of which are critical for the demonstration phase and some of which can be addressed later as follows:

- **Ship motion forces:** The demonstration system should be capable of both cargo movement handling and stowage during roll, pitch and heave in high sea states. It should be able to safely restrain the cargo as defined above and both the shuttle and satellite should operate satisfactorily.
- **Structural integration and alignment:** The system should be designed to integrate with various ship hold configurations, attaching directly to primary structure. If there are alignment critical components (e.g. tracks) in the system, then adjustments need to be designed into the ship interface. It is recognized that ultimately ASRS systems will be designed specifically to fit the particular ship on which they are implemented, but the demonstration should consider generic ship structure to the extent possible. The intent is to determine critical interface design parameters.
- **Shock:** This is a future consideration for implementation in some ship classes. It does not need to be implemented in the demonstration project but it should be considered in development of the ship interface approach.
- **Corrosion:** This is a consideration for operational ASRS implementations in future ship platforms. For demonstration purposes, it should be considered where convenient but it is not necessary to make wholesale design or material changes. Instead the critical design points should be identified and addressed for future design detail and/or material substitution. The demonstrator should be monitored for corrosion to verify the analytical results.

Standard Payload Interface (Other): The Standard Payload Interface (SPI) should be evaluated for potential application with the ASRS system and considered as an optional demonstrator phase. NAVSTORS SPIs are a reasonable means for interfacing with most ammunition pallets and weapons.

Stowage density (Other): Stowage density is a major consideration for ASRS; however, it is not necessary to redesign for the demonstration project. Instead, the standard design should be evaluated for alternative component and/or installation redesign approaches that will improve stowage density. The demonstration project will help establish realistic boundaries.

Selective offload (Other): It is assumed that the ASRS will have fully automated selectivity. The demonstration project should be structured to show how the selectivity algorithms work and to provide a comparison of selectivity vs. stowage density in terms of cycle time requirements. If alternative approaches for stowage configuration are feasible, the demonstration project should be based on the one with the best selectivity to verify performance against modeling and simulation (M&S) projections. The M&S projections can then be used to validate selectivity vs. stowage density trade-offs for alternative configurations.

6.7. Other Technology Development

Specific technologies that need to be addressed which are not currently supported by ONR-funded projects include:

Automated doors and hatches (actuation and control) (FY06/S&T): Standard electric actuators can be integrated with doors and hatches to provide automatic operation in support of cargo

movement. The actuators can be integrated with the shipboard warehouse management system (SWMS) and/or autonomous vehicles to coordinate opening/closing with vehicle movements.

Autonomously guided vehicle (AGV) (TBD/S&T): Material handling equipment that can be operated autonomously may be linked with automated task management systems to simultaneously reduce shipboard workload and improve cargo handling efficiency. AGVs might work independently, in accordance with instructions generated by an automated task management system, or collaboratively in conjunction with a master vehicle that may be manned. Incorporation of AGVs into shipboard logistics will require advancements in automated task management systems, as well as sensing, measuring, and tracking systems that can provide the fidelity necessary for safe shipboard maneuvering and control.

Selective loading/unloading platform (TBD/R&D): At numerous points in the intra-ship cargo handling supply chain, bottlenecks exist as a result of hand-offs between material handling equipment. Some of these handoffs result from the inability for material handling equipment to self-load and unload (for example, elevator platforms require material handling equipment in holds and on deck to transfer cargo on and off the elevator platform). This results in waiting periods while an elevator platform is being loaded or unloaded. These waiting periods often extend to operational periods before a platform is available to be loaded or unloaded. A platform that incorporates self-loading and unloading capability would mitigate these waiting periods by permitting MHE to continue operating elsewhere while an elevator platform is loaded and unloaded. The DRB envisioned similar loading and unloading mechanisms may be applicable to maneuvering material handling platforms. Taking full advantage of this capability may require selective loading and unloading capability, such that a platform may load or unload specific cargo (e.g. pallets/packages) from multiple locations.

Automated task management (TBD/R&D): Standard commercial warehouse management system (WMS) software can be readily adapted to ship cargo movement operations, expanding on the implementation already in final stages of development for T-AKE. SWMS controls cargo handling operations from a centrally managed perspective, optimizing for overall efficiency. It ensures cargo handling and stowage rules are followed. SWMS can communicate with personnel through hand-held, wireless terminals and, ultimately, can communicate directly with vehicles, elevators, ASRS and other cargo handling systems.

High power density electric/electric-hybrid actuator (Other): Emerging technologies in support of FNC Expeditionary Logistics product lines may require actuators (both linear and rotary) that exceed the limits of existing capability. These enabling technologies have requirements for high torque/power density with rapid response times (low inertia). The SUSD product line requires advanced actuators in support of vertical lift, automated doors and hatches, and lifting and articulation associated with motion compensated material handling. Work related to the HiCASS product line has demonstrated that motion compensated crane applications stretch the limits of existing actuator technology. In parallel with these emerging requirements, efforts to reduce shipboard maintenance workload place pressure on ship designers to reduce reliance upon hydraulic systems in favor of all-electric systems. Significant development is necessary to develop electric actuator technology that can provide the same power and torque density as hydraulic systems.

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APPENDIX A: PROJECTS REVIEWED

The DRB conducted design reviews on the four ONR SUSD projects. The primary purpose of the project design reviews was to assess the applicability, viability and maturity of the science and technologies involved and assess the projects potential to transition to the Acquisition Community for R&D continuation. The results of the reviews were provided to ONR and the specific Project Teams. In addition, several additional technologies showing promise to achieve FNC goals were given a less formal review. The specific "technologies" within each of the project are identified for information.

Linear Electric Drive Technology (LEDT)

LEDT is a cargo movement system powered by Linear Induction Motor (LIM) or Linear Synchronous Motor (LSM) technology. The system is intended primarily for ropeless vertical movement on advanced carriers and is capable of powered motion in the vertical and horizontal planes, and also transitioning between planes of motion. This concept is directly applicable to other ships and may have substantial benefit where multi-plane motion can be integrated into the overall ship design (e.g. MPF(F)). Technology development includes a prime mover, braking system, braking and control system for the conveyor. The system seeks to reduce manpower and workload requirements through robotics and system controls. It offers improved ship structure integration via vertical movement trunks that follow hull contours. Additionally it offers improved elevator shaft utilization, and provides larger load handling ability resulting in increased throughput speed.

Specific technologies included in the LEDT Project are as follows:

- **Ropeless Concept** – Because it is ropeless, this concept eliminates restrictions on operation with the ballistic hatch(es) closed.
- **Removable Platform** – This concept includes transition from vertical to horizontal platform travel enabling the platform to exit the trunk. The removable platform permits loading/unloading outside the trunk, thus enabling the possibility for multiple platforms within a single trunk. This feature is essential to increasing overall strike down/up goals.
- **Directional Movement** – This concept enables vertical, horizontal and diagonal movement of the platform. On future platforms where trunk layout flexibility exists, this concept can also provide more extensive combined horizontal/vertical movement of cargo.
- **Building Block** – Linear electric motors have other potential applications on all-electric ships. While not a specific task within this project, qualification to MIL-SPEC standards will provide the base for future applications.

Human Amplification Technology (HAT)

HAT is an enabling technology that has many potential applications on ships. From a strike-up/down perspective, the primary benefit is enabling cargo movement, end-to-end, without handoffs. HAT is independent of the ship and, therefore, has application to virtually every platform, new design or backfit. The HAT project will develop a proof of concept transporter. HAT was discussed in several variations as follows:

HAT Transporter (HAT-T) – A self-powered omni-directional platform that is guided by a single operator. The control system will use HAT and ship motion compensation to minimize human effort in significant material handling tasks. Sustained operation above/below deck without power tether will be possible.

HAT (Heavy) Lifter (HAT-L) – Building on the HAT-T, the HAT-L will enable loading and unloading of the platform further integrating HAT and ship motion compensation into the lifting process. Tethered and untethered (power) operation will be possible above/below deck. Sustained operation will be through tethered power or an IC engine in an above deck variant.

HAT Sailor (Strength-Assist) (HAT-S) – HAT-S will be a smaller, more dexterous platform capable of operation in more confined environments but at reduced payload. One Sailor/Marine can lift and precisely position single items up to 500 lbs. Similar to HAT-L, tethered and untethered (power) operation will be possible above/below deck. Sustained operation will be through tethered power or an IC engine in an above deck variant.

The basic analytical methodology for the HAT approach has been developed and proof-of-principle demonstrations have been accomplished showing a single human precisely (sub-millimeter accuracy) lifting, handling, and assembling payloads of up to 5,000 lbs (the lift amplification mode). Similarly, a single human has demonstrated precisely pushing, pulling, and maneuvering (push/pull amplification mode) loaded omni-directional wheeled platforms of up to 10,000 lbs. The intuitive human interface ensured precise, stable control of these systems under a full range of motion (six degrees of freedom for the lifter) by even non-technical personnel with an average of less than two minutes of instruction. The HAT project is intended to supplement existing HAT technology building blocks with ship specific features.

Specific technologies in the HAT project include the following:

- Omni-directional movement controlled by an operator – Development of a control system for OCILOW wheel transport platform. OCILOW wheels use standard tires and eliminate the issue of omni-directional travel on existing deck structures. Omni-directional movement will provide improved accessibility for cargo handling, especially in tightly packed holds.
- Ship motion compensation – The intent is to develop control algorithms that will measure and automatically compensate for ship motions in high sea states. This will enable a single operator to safely move the cargo throughout the ship.
- Self-loading (future) – HAT-L and HAT-S
- Equipment/weapons handling (future) – Integrating force feedback technology (already existing) with HAT-L can enable single-person operations where heavy loads (up to 3,000 lb) and tight fit are required.
- Autonomous operation (future)

Automated Stowage and Retrieval System (ASRS)

Automated Stowage and Retrieval Systems are prevalent throughout the commercial warehousing industry but the shipboard environment demands features that do not exist in land-based warehouses. The ASRS project is a modification of one existing COTS warehouse material handling system for a marine environment in a single hold. Once the marinization issues are technically solved and demonstrated, ASRS has a broad range of potential applications on ships. ASRS technology is essential to the MPF(F) program in particular. The system seeks to reduce manpower and workload requirements through robotics and system controls; provide for selective offload, and larger load handling ability resulting in increased throughput speed.

Specific technologies included in the ASRS Project are as follows:

- Automated handling of cargo (pallets, ammunition, weapons)
- Cargo constraint while in motion

- Automated cargo constraint in stowage
- Automated inventory control and cargo management (warehouse management system)
- Automated handling of large loads (Quadcons, ISO containers) in the future

Advanced Weapons Elevator (AWE)

The AWE is a ropeless elevator concept that employs a new hoisting mechanism for weapons elevators to improve weapons handling rates with reduced maintenance and enhanced utilization flexibility. While initially targeted for aircraft carriers, this concept is directly applicable to other ship classes. The primary technology is a hybrid rack and pinion system driven by a hypocycloid actuator with condition-based maintenance built in. The system includes a new, faster operating ballistic hatch and highly dexterous mobile elevator carriage. The benefits of this new system will be substantially increased rates of material strike-down during resupply, increased aircraft sortie rates, improved elevator shaft utilization and the potential for increased reliability and reduced maintenance.

Specific technologies included in the AWE Project are as follows:

- **Performance Modeling and Prediction** – The performance modeling assessment is a deterministic discrete event model simulation being accomplished to reduce risk in the AWE project. The assessment considers the configuration dependencies of physical structures, control programs, and input queues to optimize system configuration and controls.
- **Ropeless Concept** – Because it is ropeless, this concept eliminates restrictions on operation with the ballistic hatch(es) closed.
- **Electric Actuator** – The actuator is the elevator platform driver. Rack and pinion climbing gears driven by actuators are located at each corner of the platform and are simultaneously controlled to raise and lower the platform. The actuator design is rugged and provides a significantly increased torque density compared with existing electric actuators. The climbing gear will incorporate a failsafe brake and low maintenance features.
- **Building Block** – The electric actuator included in this project is one of a family of standard actuators that have other potential applications on all-electric ships. While not a specific task within this project, qualification of one actuator to MIL-SPEC standards will provide the base for future applications.
- **Guide Rails** – The guide rails will incorporate racks for the climbing gear to engage, guide roller tracks for climbing gear alignment, and a power and control rail feature. The guide rails also provide the primary ship interface.
- **Removable Platform** – A removable elevator platform is envisioned which can enter and exit the elevator trunk. The platform will connect to the climbing gear with a suspension system and quick connect/disconnect fixtures. The removable platform permits loading/unloading outside the trunk, thus enabling the possibility for multiple platforms within a single trunk. This feature is essential to increasing overall strike down/up goals.
- **Ballistic Hatch Redesign** – An electro-mechanically operated hatch is envisioned. Reducing power requirements by engineering hatch trajectory is being investigated. Integrating Guide Rails into the hatch to transition through the hatch is the current plan. Integration of the hatch and platform operation is necessary to improve overall throughput rate for the platform(s).

The main focus of work to date has been on the electric actuator and the performance assessment.

Naval Stowage and Retrieval System (NAVSTORS)

NAVSTORS is a system of components that when taken together enables automatic acquisition, manipulation and transportation of weapons and cargo payloads between elevators and stowage. The envisioned system components are as follows:

Standard Payload Interface (SPI) – The SPI is a rack designed to interface with the great multitude of Navy weapons and stores containers and pallets, and provide the handling equipment with a standard interface for both handling and securing at sea. The SPI uses existing fork truck slots and enables payloads to be nested resulting in higher vertical stowage density and increased stability. A unique feature of the SPI is that it will enable stacking of built-up ready service weapons. A sliding shelf/drawer version of the SPI was shown for small package handling and stowage.

Robotic Payload Carrier (RPC) – The RPC is a self-propelled platform which interfaces with the SPIs. The RPCs, or a passive externally driven version, will enable selective offload by shuttling fore and aft or athwartships in a slide-puzzle fashion, in the cargo hold, automatically transporting the selected payload the elevator transfer area.

Universal Loading Tray (ULT) – The ULT is a passive platform which can be externally driven on or off an elevator, can interface with an omni-vehicle, or interface with a standard UNREP rig for ship to ship transfer.

Payload Stacker/Unstacker – The Payload Stacker/Unstacker uses a combination mast/overhead rail to transfer the payloads between the RPCs and the ULTs in the elevator transfer area.

Controls and Automation – An indexing algorithm to enbale selective offload is being developed along with a control system hardware and software specification.

The main focus of work to date has been on the SPI and the Pallet Carrier. The SPI has been prototyped and installed on a ship motion simulator.

Specific technologies addressed by the NAVSTORS project include:

- Automated handling of cargo (pallets, ammunition, and weapons)
- Cargo constraint while in motion
- Automated cargo constraint in stowage
- Automated inventory control and cargo management (warehouse management system)

Omni-directional Vehicle (ODV)

The ODV is a highly maneuverable autonomous transport system for shipboard material movement, based on existing, proprietary Ilonator wheel technology. The ODV system provides significant capability improvement over existing materiel handling equipment (MHE). In addition, this advanced system concept in its autonomous control configuration directly supports the Navy's reduced manning goals.

Specific technologies in the ODV project include:

- Omni-directional movement – The basic platform technology has been in existence for a number of years and has had some laboratory testing for potential shipboard application.
- Remote control – This project is initially looking at remote (tethered, wireless) control of the platform as a step toward autonomous operation.
- Autonomous movement (future)

Autonomous Vehicle Logic

By use of a discrete event simulation, evaluation and trade-offs can be made between various notional automated material handling systems. Guidance and control algorithms will be evaluated under operational scenarios, and be designed to have human presence in the process, but be upgradeable to complete autonomous operation in future systems as the technology develops. This project will develop navigation and control software to be integrated with omni-directional platforms.

Specific technologies include:

- **Autonomous movement without fixed path** – On-board navigation sensors will enable the platform to travel point to point without a fixed path or external controls. This would enable, for example, movement from CONREP station to elevator across the hanger deck of a CVN.
- **Parallel handling** – Proprietary "swarm logic" would enable optimized movement of multiple autonomous platforms in parallel.

Robotic Shipboard Weapons Loader/High Torque Actuator

The robotic shipboard Weapons Loader will use omni-directional (Ilonator) wheels to position an aircraft weapon and enable a single operator to lift and position the weapon using a robotic manipulator. High torque actuators will be developed for use in the loader.

Specific technologies include:

- **Equipment/weapons handling** – Integrating force feedback technology to enable single-person operations where heavy loads and tight fit are required. This is currently working under a separate NAVAIR contract.
- **Electric Actuator** – The actuator is being designed to replace hydraulic cylinders in a wide variety of applications. Both a high torque actuator and a linear version were discussed, though development efforts have focused on the high torque version.

Building Block – The electric actuator included in this project is one of a family of standard actuators that have other potential applications on all-electric ships. While not a specific task within this project, qualification of one actuator to MIL-SPEC standards will provide the base for future applications.

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APPENDIX B: MAPPING TECHNOLOGIES TO PLATFORMS (COMMONALITY)

Mapping Enabling Technologies to Platforms

The following table identifies the specific technologies associated with each SUSD project as previously described in Appendix A and summarizes how these technologies relate to various platforms.

The intent of this breakdown is to identify technologies that have a high probability of successful transition and broad application potential as well as providing specific focus areas within the overall S&T projects.

- *E* - *Essential* means that this technology is required for the particular platform to complete its mission.
- *B* - *Beneficial* means that the technology will help the particular platform improve cycle-time, reduce manning or both but it is not an essential requirement.
- *A* - *Acceptable* means that this technology can be applied across platforms in order to support standardization but the technology in itself will not provide substantive cycle-time or reduced manning benefit.
- *n/a* - *Not applicable* means that this technology cannot or should not be considered for application to this particular platform.
- *Essential Baseline Technology* - indicates an enabler of higher level technology objectives that is not specific to a particular platform, but is an essential enabler for a technology independent of a particular platform (i.e., ship motion compensation is an essential building block of human amplification technology).

Table 7: Mapping Technologies to Platforms

	Platform Applicability						
	CVN 21	MPF(F)	T-AOE(X)	LHA(R)	CLF Backfit	CVN/LHA Backfit	Combatant or Amphib
High Rate Vertical & Horizontal Movement Technologies (Linear Electric Drive and Rack & Pinion)							
Vertical/horizontal transition	B	B	B	B	n/a	n/a	B
Removable platform	E	B	B	B	n/a	n/a	B
Multiple platforms	E	B	B	B	n/a	n/a	B
Payload capacity	E	E	E	E	E	E	E
Braking	Essential Baseline Technology						
Positioning and control	E	E	E	E	E	E	E
Ballistic hatch transition	E	n/a	n/a	n/a	n/a	n/a	n/a
Weight, volume, and power impact (high performance materials)	Essential Baseline Technology						
Compact, Agile Material Mover Technologies (Human strength amplification)							
Transporter (HAT-T)	B	B	B	B	B	B	B
OCILOW wheel concept	B	B	B	B	B	B	B
Ship motion compensation algorithms	Essential Baseline Technology						
Ship Motion Simulator	Essential Baseline Technology						
Lifting devices (HAT-L & HAT-S, other)	B	B	B	B	B	B	B
Autonomous operation/navigation	B	B	B	B	B	B	B
Cargo restraint in motion	B	E	B	B	B	n/a	B
Train mode for transporters	B	B	B	B	B	B	B

Table 7: Mapping Technologies to Platforms

	Platform Applicability						
	CVN 21	MPF(F)	T-AOE(X)	LHA(R)	CLF Backfit	CVN/LHA Backfit	Combatant or Amphib
Automated stowage and retrieval							
Automated cargo restraint in motion	B	E	B	B	B	n/a	B
Automated cargo restraint in stowage	B	E	B	B	B	n/a	B
Adaptability to package size/shape (nesting optimization)	B	E	B	B	B	n/a	B
Automated container breakout and repackaging	n/a	E	n/a	n/a	n/a	n/a	n/a
Standard payload interface (NAVSTORS)	B	B	B	B	n/a	n/a	B
Marinization (e.g., shock, ship motion forces, corrosion, and structural integration and alignment)	Essential Baseline Technology						
Stowage density	B	E	E	B	E	n/a	B
Selective offload	B	E	E	B	E	n/a	B
Other (technology solutions not currently being pursued within established SUSD projects)							
Automated doors and hatches (actuation and control)	E	B	B	B	n/a	n/a	B
Autonomously guided vehicle (AGV)	B	B	B	B	n/a	n/a	A
Selective loading/unloading platform	B	B	B	B	B	B	B
Automated task management	E	E	E	E	E	E	E
High power density electric/electric-hybrid actuator	Platform Independent – An Enabler						

APPENDIX C: WORKSHOP "STAKEHOLDER IDENTIFIED" CULTURE/PROCESS CHALLENGES

During the course of its work reviewing the various shipboard internal cargo movement-related S&T projects funded by ONR, the industry Design Review Board (DRB) noted the possible existence of number of cultural and procedural influences that were, to varying degrees, inhibiting the successful transition of new technologies to Navy platforms. In addition to their recommendation that a workshop be held to identify the key technology challenges warranting S&T funding and transition, they also recommended that stakeholders attempt to identify the key process and culture challenges impeding new technology transitions.

Following the recommendation of the DRB, the National Shipbuilding Research Program conducted a facilitated two-day workshop that included presentations, breakout sessions and group discussions which were specifically designed to gather the necessary data for the creation of a roadmap to focus FY '04 – '06 S&T funding for Shipboard Internal Cargo Movement. Participants were comprised of stakeholders from the various platform sponsors, Navy and Marine Corps engineering and acquisition communities, fleet and force commands, shipbuilding industry, logistics agencies, and oversight authorities. This wide array of organizational representation was necessary to ensure that relevant concerns and issues were fully expressed and understood by other stakeholder organizations. The workshop participants' observations regarding the key process and culture challenges keeping new cargo movement technologies from transitioning to future Navy platforms are summarized in this section. The observations expressed in this section are provided for information purposes only and do not necessarily reflect the official opinions of the Office of Naval Research, the National Shipbuilding Research Program, or the parent organization of the individual workshop participant.

The numerous observations contributed by the stakeholders can be categorized into five main areas which are summarized in the table below. Each area is explored briefly in the paragraphs following.

Table 5: Stakeholder Identified Culture/Process Challenges and Key Issues

Challenges	*Key Issues*
Risk Aversion	Risk exists at many levels and can impede new technology development and transition.
Change Aversion	A culture resistant to change can have negative consequences for technology transition.
Centralized Technology/ Innovation Authority	A centralized technology/innovation organization is needed to provide a clear vision and champion projects through the approval process.
Process	The technology innovation process needs to be streamlined.
Funding	Consistent funding for both S&T and R&D can speed technology development and transition.

Risk Aversion

The very nature of S&T research is characteristically risky, but a number of cultural and procedural difficulties increase the risk of developing new technologies to enable advanced Fleet capabilities. Examples of these difficulties include apparently unclear or non-existent performance requirements, lack of early-on

R&D funding commitments, changing ship design schedules, lack of vision, etc. These difficulties increase risk throughout the enterprise including the areas of:

Programs/Personnel: Adopting new technology into platforms is perceived as risky for programs and the people who manage them, and the perceived penalties far exceed the rewards. New technology is inherently uncertain, and uncertainty equates to added risk. Program managers resist including advanced technologies into new platforms for fear of resultant delays, design changes, and cost or schedule overruns; most of which can mean reduced funding or even termination of their program, which in turn may result in personal penalties. Conversely, the rewards for successful technology integration are virtually non-existent for programs and personnel alike.

Project Teams: Innovation can be slowed as fewer companies are less likely to risk time, money and resources building project teams to respond to Broad Agency Announcements (BAA) or Research Announcements (RA) given the inherent threat of not being able to obtain committed R&D funding to transition S&T into new platforms. Without committed R&D funding at the outset projects could face funding delays, team dissolution and possible reconstitution costs.

Shipbuilders: Shipbuilders, and particularly the lead design yard for a specific platform, face significant risk incorporating new technologies into the design of new ships. New technology may necessitate additional employee hiring, design changes and delays, alternative/advanced production methods, added contract costs, etc. Obviously, these added expenses quickly become losses if the technology in question fails to transition from S&T to R&D for lack of R&D commitment or other reasons. Shipbuilders are reluctant to risk build schedules for unproven technology, as are the personnel responsible for the associated design decisions.

Commercial Vendors: Inherently long lead times, difficult design process, and limited business case contribute to hesitancy on the part of potential commercial industry partners to assume risk in committing to commercialize new technology for a limited number of platforms.

Change Aversion

Most longstanding endeavors involving people are averse to change for a number of reasons and this aversion to change can have a negative effect on technology advancement both during the development stage and even after the technology has transitioned to an operational shipboard system. The programmatically-minded might argue that system transition to the shipboard environment alone should qualify as success; however change aversion can negate intended performance improvements or capabilities. There have been instances when new technology is ignored by the intended end-user. Workshop participants identified a number of factors resulting in resistance to change that negatively impacts the development of new technology including:

- Age and attitude of leadership and talent pool
- Lack of contemporary knowledge
- The ADITW Syndrome (always done it that way)
- Tribal training and memory system
- Goals and values – "just get it done." This is also risk aversion.
- Mental models
- Competing priorities (e.g. Propulsion/Weapons/Quality of Life/Cargo)
- Reward and recognition (incentive) systems, or lack thereof
- Low up-front involvement of junior personnel

Additional factors thought to be contributing to a change-resistant culture include stringent statutory and regulatory environments, and resistance to manpower reductions.

Centralized Technology/Innovation Authority

The stakeholders identified the lack of a provider to articulate and communicate a clear vision with meaningful, understandable and achievable performance parameters across the multitude of organizations involved in the process as one of the major impediments to technology innovation. Currently little linkage exists between Fleet needs, ONR investment and acquisition buy-in. This vision provider could incorporate end-user/Fleet input early in the requirements definition process, compare similar requirements across platforms and subsequently identify key component technologies for funding that would become the S&T building blocks for new systems. Projects today face almost insurmountable odds on the road to transition. They are easy to veto and difficult to champion. System (e.g. material handling) sponsors, if they exist, more often than not lack the necessary authority and resources to engage the multitude of opposing forces. Establishing an overarching command authority who acts to champion innovation and technology transition would greatly increase the probability that innovative technology will enter the Fleet. It only takes one of the multitude of organizations involved in the approval process to delay or even terminate a project, as can the numerous and frequently outdated statutory and regulatory roadblocks. The lack of end-to-end supply chain management exacerbates the problem and contributes to gaps and stove-pipes. Frequent turnover of project personnel is another factor that can change both emphasis and direction of technology development.

Process

The process of technology innovation needs to be streamlined. Effective collaboration is vital to project development and is very difficult to achieve in today's environment. Competitive requirements and FAR generally tend to discourage open collaboration. Greater cooperative interaction between the Research and Acquisition communities would improve trust and communication and possibly accelerate the transfer of developing technology from S&T to R&D.

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APPENDIX D: GLOSSARY

AGV	Autonomously Guided Vehicle
ASRS	Automated Storage and Retrieval System
AIT	Automated Inventory Tracking
ATI	Advanced Technology Institute
AWE	Advanced Weapons Elevator
BAA	Broad Agency Announcement
CLF	Combat Logistics Force
CONREP	Connected Replenishment
COTS	Commercial off the Shelf
CVN21	Carrier Nuclear Powered
DoD	Department of Defense
DDX	Destroyer (surface combatant) follow-on to DDG class
DRB	Design Review Board
EXLOG FNC	Expeditionary Logistics Future Naval Capabilities
FIUL	Fleet Issued Unit Load
HAT	Human Amplification Technology
HiCASS	High Capacity Alongside Sea Base Sustainment
ISO	International Standards Organization
JDAM	Joint Direct Attack Munition
JILWG	Joint Intermodal Logistics Working Group
JMIC	Joint Modular Intermodal Container
LCS	Littoral Combat Ship
LEDT	Linear Electric Drive Transport
LHA	Amphibious Assault Ship
LHA(R)	Replacement for the Tarawa class ship (Amphibious Assault Ship)
LHD(R)	Replacement for Amphibious Assault Ship
LMSR	Bob Hope-class of large medium speed, roll-on/roll-off sealift ships
Marinization	Process of adapting commercial systems to marine environment (shock, ships motion, etc.)
MHE	Material Handling Equipment
MPF(F)	Future Maritime Pre-positioning Force
NAVSTORS	Naval Stowage and Retrieval System
NSRP	National Shipbuilding Research Program
NSWC-CD	Naval Surface Warfare Center-Carderock Division
ODV	Omni Directional Vehicle
ONR	Office of Naval Research
PEO	Program Executive Office
Quadcon	Quadruple modular lightweight container for consumable supplies.
R&D	Research and Development
RA	Research Announcements
RBC	Reusable Bulk Container
Ropeless Elevator	Elevator designed without cables used for vertical movement
SBIR	Small Business Innovative Research
S&T	Science and Technology
SOW	Statement of Work
SUSD	Strike-Up/Strike-Down. This refers to internal cargo movement on ships. Strike-down is the process of receiving material from a ship

	onload point (the CONREP or VERTREP station, wet well, or other loading point), decomposing from the shipping configuration (when/where necessary), moving the material to the designated stowage location, and securing the material. Strike-up is the process of locating the required material in its stowage location, decomposing from the shipping configuration (when/where necessary), configuring the material for consumption/shipping, and moving the material to the shipboard location where it will be consumed, used, or transferred off the ship.
SWMS	Shipboard Warehouse Management Systems
T-ADC(X)	Auxiliary Dry Cargo Carrier
T-AOE(X)	High speed vessel, designed as oiler, ammunition and supply ship
TRL	Technology Readiness Level
UNREP	Underway Replenishment
VERTREP	Vertical Replenishment

APPENDIX E: SUSD EXIT CRITERIA

Criteria	Current Capability	Minimum	Goal
Increased System Capacity	Various, many ships require manhandling. 4,000 lb forklifts are common.	Handle a variety of Naval packaging and weapons up to 6,000 lbs TRL* 6	Handle a variety of Naval packaging up to 12,000 lbs
System Operating Conditions	Current shipboard systems do not have a consistent operating condition definition.	Able to operate continuously with the rated load with a 21° [TBR] static heel and maintain load control with a 30° [TBR] static heel. TRL 6	Able to operate continuously with the rated load with a 23° [TBR] static heel and maintain load control with a 50° [TBR] static heel.
Precision Control using Force Compensation	SUSD systems achieve precision control in a land-based application only.	Achieve $\pm$ 0.5" load control positioning tolerance in a sea state 5 environment. TRL 6	Achieve $\pm$ 0.03" load control positioning tolerance in a sea state 5 environment.
Workload Reduction for Mobility Equipment	Current Mobility Equipment is work load intensive, particularly with heavier loads	Reduce workload to a single person able to transport and maneuver heavy weapons and stores payloads. TRL 5	Reduce workload to a single person able to simultaneously transport and maneuver multiple heavy weapons and stores payloads.
Footprint for Mobility Equipment	Current shipboard equipment has a suitable footprint.	Footprint no larger than 10% greater than that of equipment being replaced. TRL 6	Footprint equivalent to that of equipment being replaced.
Weight for Mobility Equipment	Current shipboard equipment has a suitable weight.	Weight no more than 10% greater than that of equipment being replaced. TRL 5	Weight equivalent to that of equipment being replaced.
Deck Pressure for Mobility Equipment	Carrier decks are suitable for current mobility equipment.	Deck pressure beneath the wheels shall be limited to (deck pressure for primary decks) psi at the rated load. TRL 5	Deck pressure beneath the wheels shall be limited to (deck pressure for non-primary decks. May be same as minimum) psi at the rated load
Maneuverability for Mobility Equipment	Equipment is not highly maneuverable.	SUSD mobility equipment shall be fully maneuverable in confined spaces. TRL 6	SUSD mobility systems shall be capable of rotating within their own footprint.
Powering for Mobility Equipment	Current systems support replenishment requirements.	Non-tethered equipment shall operate for 6 hours at a 50% duty cycle without power resupply. TRL 5	Non-tethered equipment shall operate for 8 hours at a 65% duty cycle without power resupply.
Deck Loading for Automated Warehouse Equipment	Current structures in the magazines are capable of supporting required loads.	Primary deck support scantlings in way of equipment shall not require modification. TRL 5	Magazine structure shall not require modification.
Stowage Density for Automated Warehouse Systems	Current stowage densities meet needs.	No loss of stowage density from current densities. TRL 5	Improved stowage density over current densities.

Criteria	Current Capability	Minimum	Goal
Selective Offload for Automated Warehouse Systems	Selective offload capable only with large work parties and staging space.	Ability to automatically call up a selected load and deliver it to the loading station without additional human intervention. TRL 6	Ability to automatically call up a selected load and to automatically capture and release the loads.
Powering for Vertical Movement and Automated Warehouse Equipment	Power requirements for existing systems can be supported by ship power.	Power gain of less than 20% over the system being replaced. TRL 5	No power gain over the system being replaced.
Increased Throughput Speed for Vertical Movement Equipment	Slow, does not meet future requirements.	Improve elevator shaft utilization by a factor of 2. TRL 6	Improve elevator shaft utilization by a factor of 5.
Reliability for Vertical Movement Equipment	Current elevators have reliability/availability concerns.	Partial redundancy with condition monitoring and “limp home” feature. TRL 5	A 100% redundant system.
Life Cycle Cost	Life cycle cost of existing systems is adequate.	Life cycle costs shall be equivalent to systems being replaced. TRL 4	Life cycle costs shall be less than systems being replaced.
Maintainability	Current systems are difficult to maintain.	Modularity of components to the greatest extent practical. TRL 5	Improved maintainability and availability over systems being replaced.

* TRLs are estimated.

APPENDIX F: TECHNOLOGY READINESS LEVELS

Technology Readiness Level

DOD 5000.2-R Appendix A6-4

- SYSTEM QUALIFICATION
- SYSTEM/SUBSYSTEM DEVELOPMENT
- TECHNOLOGY DEMONSTRATION
- TECHNOLOGY DEVELOPMENT
- RESEARCH TO PROVE FEASIBILITY
- BASIC TECHNOLOGY RESEARCH

9	Actual Application of the Technology in It's Final Form and Under Mission Conditions.
8	Technology Has Been Proven to Work in It's Final Form and Under Expected Conditions.
7	Prototype Near or at Planned Operational System. Major Step From Level 6, Requiring the Demonstration of an Actual Prototype in an Operational Environment.
6	Representative Model or Prototype System, Which Is Well Beyond the Breadboard Tested 5 Is Tested in a Relevant Environment
5	Fidelity of Breadboard Technology Increases Significantly Enough to Justify Being Ready for Testing in a Simulated Environment
4	Basic Technology Components Are Integrated to Establish That the Pieces Will Work Together.
3	Active Research and Development Is Initiated. This Includes Analytical and Laboratory Studies to Physically Validate Analytical Predictions of Separate Elements of Technology.
2	Invention Begins. Once Basic Principles Are Observed, Practical Applications Can Be Invented. The Application Is Speculative and There Is No Proof of Detailed Analysis to Support the Assumption.
1	Lowest Level of Technology Readiness. Scientific Research Begins to Be Translated Into Technology's Basic Properties.

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APPENDIX G: SUSD FOR AIRCRAFT CARRIERS – A SHIPBUILDER'S VISION

As part of the data collection process conducted during this effort, members of the DRB were asked to apply their shipbuilding experience and brainstorm a vision for how an advanced integrated system for strike-up/strike-down might function on various future platforms. This appendix is that vision for CVNs and in no way is it intended to represent the views or opinions of the shipbuilding industry as a whole or the respective NAVSEA program office. It is provided here as background information and is intended to provide the reader with a better understanding of shipboard internal cargo movement challenges and potential solutions.

Current cargo handling on aircraft carriers is inherently a convoluted set of processes which are extremely time consuming, heavily manpower intensive, and exceedingly intrusive on other critical functions. With approximately 400 storerooms, magazines, freezers, chill rooms, lockers, etc throughout the ship handling the full range of possible cargo items through a variety of passageways, doors, hatches, and scuttles, using a large assortment of support equipment, the carrier is likely the most complex warehousing system conceivable. There are unique stowage and handling problems associated with virtually every category of cargo on the ship and each deserves thorough analysis for optimization but, for the purposes of this vision statement, we'll focus on those that have the most direct impact on mission capability and base the discussion on CVN 21 Operational Requirements Document (ORD) specified parameters. With the exception of chilled food, hazardous materials, and flammables, basic stores endurance is required to be at least 75 days. The significant exceptions to this are:

- Aviation Maintenance Material (aircraft spare parts, etc.) required to support unreplenished combat air operations. Endurance is 72 days at the sustained objective sortie rate (an average of 220 sorties per day) and 18 days at the surge objective sortie rate (an average of 310 sorties per day).

- Shipboard Self-Defense Weapons, Ordnance and Countermeasures required to support self-defense combat operations. Endurance is a minimum of 4 days of self-defense operations (threshold). Material support requirements are not easily defined but would be very limited relative to other material support requirements.

- Aviation Fuel Capacity to support combat air operations. Endurance is for sufficient Aviation fuels (JP-5) capacity to support unreplenished combat air operations for 6 days (threshold) or 10 days (objective) of sustained surge (assumed to be the objective surge rate averaging 310 sorties per day). This is achievable with current carrier tankage, specific analysis is available.

- Aviation Weapons, Ordnance and Countermeasures Capacity to support combat air operations. Endurance is for sufficient capacity to support unreplenished combat air operations for 4 (threshold) to 6 (objective) days of surge sortie rates (averaging 270 sorties per day (threshold) to 310 sorties per day (objective)). Perhaps as big an endurance problem is meeting the sustained sortie rate requirements for this category of material. At an average of 160 (threshold) to 210 (objective) sorties per day sustained over 30 days (26 flying and 4 non-flying days) this could easily drive a larger material requirement, depending on the types and quantities of expenditures. The carrier could easily expend over 500 tons of weapons per day in some combat scenarios; more than the weight of a 30 day supply of food/provisions or virtually limitless combinations of other material except aviation fuel. But whatever the weapons expenditure rates ultimately are calculated to be (the CVN 21 Design Reference Mission is in development), this category of material clearly has the most direct impact on core mission capability and poses the greatest cargo handling challenge by several orders of magnitude.

For the reasons outlined above, this vision description is focused primarily on the aviation weapons handling system but has general applicability and potential scalability to other categories of cargo. The single largest objective for other categories of material is providing the ability to handle it by shipping configuration (pallets/containers) throughout rather than by package and that initiative is well underway.

Assumptions:

- The Navy Supply System has limited control over standardized packaging for the majority of cargo and therefore the cargo handling systems have to be flexible enough to handle various sized packages. However, standardization in packaging of non-ordnance material will be critical to effective warehousing on combatant ships that have pallet-capable handling systems (i.e. CVN 70, CVN 78, etc.).
- Flexibility of holds and magazines is essential. Load-outs are infinitely variable and will always change with platform and mission.
- Cargo and weapon handling systems must support both at-sea and pier-side operations, but must be optimized to meet at-sea replenishment operations.
- There is a trend toward all-electric operations – i.e. removal of hydraulics is preferable.
- While workload reductions are desirable they don't necessarily translate into manpower reductions.
- Carrier strike-down throughput requirements will be driven by heavy UNREP capability.
- Interoperability with joint service operations drives additional cargo compatibility considerations.
- Due to increased helicopter transfer capacity, 4000 lbs to 6000 lbs, fleet issue unit loads will increase accordingly.
- An automated open architecture warehouse management system will be integrated into shipboard information management systems and will seamlessly interface with Navy logistics management systems.

Interfaces:

An open architecture computerized system which monitors and controls shipboard material handling from a central server through a system of sensors, conventional LAN, wireless interfaces, flat-panel interfaces, personal digital assistants, and integrated interfaces on support equipment, elevators, doors, hatches, etc. is essential for naval platforms. Such a Shipboard Warehouse Management System (SWMS) will maintain a central data base which will have a seamless interface with Navy- and/or DOD-wide logistics management systems. Primary SWMS functions are:

- Manages cargo movement on the ship
- Establishes sequencing priorities
- Pre-plans load configurations
- Coordinates replenishment sequencing with the servicing source (CLF ship)
- Communicates/interfaces directly with automated system components (including transporting equipment) and responsible personnel

Automated Information Technology (AIT)/Source Data Automation (SDA) technology must be completely integrated into the supply/material movement chain. Accountability, inventory, location and

storage are transformed. Storage is the only one that needs further explanation. Man-years are wasted putting everything in its place in a storeroom. With AIT/SDA most items can remain in the same "package"/unit they were in day one at Naval Supply Center (NSC)/Defense Logistics Agency (DLA) distribution centers. Small items like electronic components may have to be binned for ease in recovery.

Cargo Delivery Systems:

Cargo delivery systems considered are the MH-60S helicopters which will provide the primary VERTREP capability and a modified (heavy) STREAM system which provides the CONREP capability. The anticipated standard will be 2 MH-60S helicopters to perform VERTREP and 2 (1 in each of the starboard hangar bay doors) of the 4 available carrier stations will be used for CONREP. The Carrier Onboard Delivery (COD) capability has only marginal impact on overall cargo handling capability and is not considered here. Pier side operations are not considered here.

Cargo/Material Handling Processes:

Current carrier cargo/material handling is based on a group of "stovepipe" systems the process interface between which is often as cumbersome as the outdated systems themselves. A cohesive, integrated system must be developed to make future shipboard warehousing seamless from requisition, to receipt of material onboard, to consumption or further distribution. Storage capacity is critical throughout the carrier so more thought also has to be given to the packaging of material that has configuration flexibility. The Navy must establish a height limit for standard cargo pallets (~36 inches) to enable double racking/stacking in typical storerooms. To maintain storage density and system efficiency, pallets/containers must be shipped full and not require shipboard breakdown/decomposition prior to the time/point of consumption. In general, the following processes are envisioned:

- Cargo/Material Handling for Strike Down During Resupply: Cargo/Material is landed directly onto (or moved immediately onto) a powered transporter at either a CONREP station or by helicopter - VERTREP. The transporter interrogates the cargo (via 2D barcode, active/passive RFID, or similar identification/data storage system), identifies the cargo, validates the cargo physical characteristics (weight and CG as a minimum), and interacts with the SWMS accordingly. Once the transporter has validated the specific cargo being handled it will be aware of its new "footprint" (interference boundaries) and be able to autonomously maneuver safely through the ship accordingly. Groups of two or more transporters may travel together to optimize use of common systems such as elevators. Once loaded, transporters supporting VERTREP will form queues near the #3 deck edge elevator; wait for the elevator to arrive at the flight deck; move as a group onto the elevator when available; travel down to the main deck on the elevator; move in mass off the elevator into the hangar bay; move in "convoy" fashion through the hangar bay to each respective weapons elevator queue interface with the weapons elevator in similar fashion and ultimately arrive at the pre-determined stowage location for the respective payload. The transporter will then either self-unload or interface with an automated stowage and retrieval system. Finally the transporter will return to the flight deck or hangar bay either empty for another cycle or be loaded with retrograde material for disposition (likely via return CONREP) prior to reuse. Movement and handling operations are coordinated/controlled by the SWMS.

- Cargo/Material Handling for Strike Up for Consumption: The specific processes for material break out, sorting, picking, assembling, etc. are too detailed to discuss here but the same transporters and similar procedures are used to distribute the material appropriately throughout the ship for consumption. Again operations are coordinated/controlled by SWMS which continues to maintain total asset visibility.

Required Technologies:

Transporters: The transporters mentioned above are self-powered, autonomously navigated, omni-directional platforms derived from the HAT project. If proven, the OCILOW should provide much better performance and stability than other omni wheel designs with the added benefit of using conventional wheels/tires. They have a human interface for precision maneuvering under/around aircraft or in other tight spaces while having the ability to navigate large open areas (flight deck, parts of the hangar bay, etc.) independently or in mass (swarm technology from Orbital Research, Inc.). There will be a need for three different sizes of these transporters (500 lb capacity, 6,000 lb capacity, and 12,000 lb capacity) and a total of over 150 total transporters will be required. Pre-established routes would not be a likely option as route variability will be critical for this system.

Automated Storage and Retrieval Systems (ASRS): The weapons stowage capacity of CVN 78 (CVN 21 class lead ship) is known to be well short of required effective volume (perhaps 257,000 cu. ft. or more). For this and other reasons identified in the NSRP NAVSTORS and ASRS reports, the only storage and retrieval systems that can be considered for the carrier will have to be based on bare-deck stowage. This can be automated by using the SWMS virtual arrangement planning tool integrated with either autonomous handling trucks, robotic arms, or a combination thereof to optimize the configuration of cargo in the magazines. This too would depend heavily on technology derived from the HAT project.

Automated Breakout and Assembly Systems (ABAS): The current process of extracting All-Up-Round (AUR) weapons from their shipping/stowage containers (breakout) is extremely time consuming, labor intensive, and requires inordinate magazine deck area (<500 sq. ft. per container depending on the type of weapon). Also, while weapons assembly tables are exceptionally well suited for assembling Viet Nam era weapons they are not effective for the assembly of modern precession guided weapons and they are labor intensive to use. Automated equipment will be critically needed to improve weapons production processes (breakout and build-up) in the magazines as well as aircraft loading. Various combinations of HAT component technologies will be capable of meeting these automation challenges.

Elevators: Vertical movement can be achieved by a number of approaches. The simplest alternative is to use existing elevators and have the transporters simply move on/off as necessary with both the elevator and the transporters directed by the SWMS. However, even with significant cycle time improvements this approach could never achieve the throughput for strike down required to meet the CVN 21 ORD performance parameter for resupply or meet the ship survivability requirements. The only way to meet the performance requirements without taking up more magazine volume is to optimize vertical shaft utilization by having multiple platforms using each shaft. This leverages work being done under the AWE project but multiple platform concepts could be applied to the LEDT project as well.

Material Handling Equipment (MHE): Common families of MHE are needed across ship classes. This goes down to subcomponents e.g. a HAT manipulator on a mobile piece of equipment can be the same manipulator on the bulkhead in a storeroom. This is an obvious manpower, training, and logistic support issue.

APPENDIX H: SUSD FOR A CLF-TYPE SHIP – A SHIPBUILDER'S VISION

As part of the data collection process conducted during this effort, members of the DRB were asked to apply their shipbuilding experience and brainstorm a vision for how an advanced integrated system for strike-up/strike-down might function on various future platforms. This appendix is that vision for a CLF-type ship and in no way is it intended to represent the views or opinions of the shipbuilding industry as a whole or the respective NAVSEA program office. It is provided here as background information and is intended to provide the reader with a better understanding of shipboard internal cargo movement challenges and potential solutions.

CLF On-load

Assumptions:

- 3 loading methods: VERTREP station(s), CONREP station(s), Cargo Crane drops (for shore loading)
- Fleet Issue Unit Loads (FIULs) weight limits are increased to 6,000 lbs.
- Heavy UNREP is employed, increasing carriage capacity to increase to 12,000 lbs.
- SWMS (Shipboard Warehouse Management System):
- Manages cargo movements on the ship
- Tracks inventory
- Preplans load configurations
- Coordinates cargo sequencing with the source system
- Communicates directly with system fixed and mobile components (the later via wireless network)

Material is landed directly onto an autonomously powered omni-directional platform and identified electronically (barcode, RFID, or similar automated data exchange system) to SWMS.

The loaded omni-directional platform moves itself to the vertical trunk (elevator) over either fixed, pre-established routes or autonomously with an onboard obstacle avoidance and navigation system.

The loaded omni-directional platform moves to the assigned hold and then into the assigned stowage location.

The omni-directional platform self-unloads the cargo. The stowage location has a passive restraint system that captures the load in place.

CLF Off-Load

Assumptions:

- 2 off-loading methods: VERTREP station(s), CONREP station(s)
- SWMS manages cargo movements and sequencing. Order from the receiving ship is automatically fed into SWMS, including optimum delivery sequence, just in time (JIT).

The omni-directional platform goes to the appropriate hold, finds the cargo, verifies using electronic identification (barcode, RFID, or similar automated data exchange system), and self-loads.

The loaded omni-directional platform moves itself to the vertical trunk (elevator) and then up to the transfer deck.

The loaded omni-directional platform moves to the assigned VERTREP or CONREP station or to a designated buffer (staging area) and gets into queue in the specified sequence with others ready to be unloaded.

Cargo is lifted directly off the omni-directional platform in turn. Note: This assumes that the pallet in which the cargo is loaded has lifting attachments that can be directly picked up. If not, or in the case of VERTREP, it may be necessary to remove the cargo from the omni-directional platform for "netting" since VERTREP will require nets for multiple pallet lifts.

Technology Notes:

The omni-directional platform is an OCILOW configuration.

The omni-directional platform may be both self-propelled and self-controlled or it may be a completely passive platform that is moved and controlled by LEDT with the stators integrated into the deck.

The pre-established routes could be "tracks" or "virtual". The pre-established routes may vary depending on the hold, staging area or passageway and type of cargo being moved. Tracks would be easier to implement initially but they provide potential disruption to the decks. Tracks may not be permanent. Virtual routes could be established using imbedded controls or external sensors/monitors. In the LEDT option, the LEDT itself defines the routes by activating the appropriate stators sequentially. Autonomous navigation would include detailed ship mapping and onboard obstacle avoidance sensors with related control logic. Collaborative interface with other omni-directional platforms would enable route optimization. A final option might be for vehicle movement to be centrally controlled by the SWMS but with a local control option for emergency stop or moving obstacle avoidance.

Vertical movement can be either of two approaches. The simplest alternative is to use existing elevators and have the omni-directional platform move on/off as necessary. To be fully automated, the elevator would need to recognize the omni-directional platform is properly loaded and then activate vertical movement. The other alternative is to eliminate the elevator platforms and use LEDT horizontal to vertical translation to move the omni-directional platforms individually.

In this vision, the whole system behaves as an AS/RS.

SWMS cargo movement and inventory control, as described above, is already developed for the T-AKE program. However, in this vision it is upgraded in two ways. Instead of providing pick-up and destination directions to the forklift operators, it provides movement control instructions to the omni-directional platform (if self-propelled) or track control system. The boundaries of inventory management operation are also extended beyond the ship to include the customer ship(s) and shore based warehouses.

APPENDIX I: SUSD FOR MPF(F) – A SHIPBUILDER'S VISION

As part of the data collection process conducted during this effort, members of the DRB were asked to apply their shipbuilding experience and brainstorm a vision for how an advanced integrated system for strike-up/strike-down might function on various future platforms. This appendix is that vision for MPF(F) and in no way is it intended to represent the views or opinions of the shipbuilding industry as a whole or the respective NAVSEA program office. It is provided here as background information and is intended to provide the reader with a better understanding of shipboard internal cargo movement challenges and potential solutions.

Assumptions:

- This vision only addresses cargo handling capabilities within an MPF(F) type ship. The MPF(F) has other functions (hospital, C4IR, etc) not addressed here and may be a family of platforms rather than a specific ship.
- The MPF(F) is essentially acting as a Fleet Distribution Center. It receives cargo from various sources, sorts, repackages, stores as necessary and then re-distributes to the users.
- A new SWMS (Shipboard Warehouse Management System) manages cargo movements on the ship and tracks inventory. But for MPF(F), this system is also integrated into the larger Navy supply system and into the dedicated systems on each activity (ship, landing craft, Marine division) that it supports.
- Incoming cargo will generally be received in ISO containers but can also come as Quadcons, pallets, or individual packages (e.g. weapon containers).
- Outgoing cargo will be supplied as Quadcons, pallets or individual packages, some of which are made up on-board. Outgoing cargo can be by VERTREP, CONREP or from the side platform (lighter) designed into the MPF(F).
- A new, standardized pallet will be used on the MPF(F). It will be self-restraining and have a built in lifting eye that can be handled directly for VERTREP or CONREP.
- All cargo will be identified by barcode, RFID, or similar automated data exchange system. If it is received without an identifier, the MPF(F) will provide one. If cargo is reconfigured on the MPF(F), the appropriate identifier will be provided.

MPF(F) On-load

A dedicated (AS/RS) system will handle ISO containers as follows:

- Skin to Skin transfer will be used to receive ISO loaded containers and send unloaded/retrograde filled ISO containers. Containers will not be retained on-board.
- Containers will be lifted aboard the MPF(F) by motion-compensated crane and deposited into a vertical track that is the start of the AS/RS.
- The container will automatically move below decks into a dedicated cargo off-loading station. The system will have a built-in queue buffer to handle multiple containers.
- The container will be unloaded onto a conveyor system (see sorting system below) that will automatically identify, sort and route cargo based on directions from SWMS.

- The empty ISO container will automatically move up a separate vertical track, loaded with retrograde material as required, and go into a queue. The motion-compensated crane will return them to the container ship.

A dedicated (AS/RS) system will handle the sorting, repackaging, and stowage of cargo. It will be highly automated but there will be storekeepers who provide oversight of automated functions and who provide manual labor if/where necessary. The sorting/repackaging system will function as follows:

- The conveyor that moves cargo from the ISO containers (above) will pass through an identifier that will scan/interrogate to verify receipt of each package. It will verify received material against the expected incoming cargo and pull aside anything that doesn't have a match for special handling.
- The incoming conveyor will feed a system that routes the individual cargo pallets, containers, etc based on SWMS guidance. Each individual cargo item will go off onto a separate track depending on the processing required.
- To the maximum extent possible, incoming cargo will be identified against its scheduled distribution (i.e. where and when it will be delivered to the end user). Based on that knowledge, it will be repackaged to suit the appropriate delivery method and it will be stowed within the MPF(F) so that it can be easily retrieved when scheduled.
- Pallets will be broken down and re-built into the delivery configuration (if known), using the standard pallets identified above.
- Bulk materials that do not have identified and scheduled end users, will be palletized by commodity and placed into storage holds where they can be accessed when necessary.
- As each cargo item completes the sorting and repackaging (if necessary) process, it will move via completely automated means to the assigned cargo hold or sending station. A combination of existing commercial AS/RS, LEDT and HAT/OCILOW technology will be designed into the ship. Actual cargo movement will be similar to that described above for typical CLF ships.
- The ship will be organized so that standardized pallets are handled entirely automatically. Irregular sizes and shapes may require some manual assistance (using HAT) during the stowage function.

Note: Bulk materials will be pulled from the cargo holds back to the sorting system if/when they require repackaging to meet new orders.

MPF(F) Off-load

The dedicated (AS/RS) system will handle movement of cargo from the holds and/or sorting area to the off-load stations (VERTREP, CONREP, side platform). It will be highly automated but there will be storekeepers who provide oversight of automated functions and who provide manual labor if/where necessary.

- All off-loading will be managed and directed by the SWMS. Cargo will be pulled from the holds in the sequence required by the receiving vessel or activity. If repackaging is necessary, the cargo will be returned to the sorting system described above.
- Cargo will move via completely automated means from the cargo hold(s) to the assigned sending station(s). A combination of existing commercial AS/RS, LEDT and HAT/OCILOW technology will be designed into the ship. Actual cargo movement will be similar to that described above for typical CLF ships.

- All cargo will be inventoried as the final step before it leaves the MPF(F). This inventory will be checked against the existing (SWMS) delivery plan and debited against the total inventory. SWMS will send a message to the receiving vessel or activity as each cargo is delivered.

Technology Notes:

Generally the notes for typical CLF ship (above) apply.

The MPF(F) will use a combination of technologies to automate horizontal/vertical movement from point to point within the ship. In general movements will be accomplished by conveyor systems rather than having omni-directional platforms. However, omni-directional platforms may be used for very large or irregular shaped loads.

The pre-established routes, either "tracks" or "virtual", will be designed into the ship.

In this vision, the whole system behaves as an AS/RS but there are separate and distinct subsystems for handling ISO containers, sorting and repackaging, and transporting and stowing.

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APPENDIX J: SUSD FOR SMALL SURFACE COMBATANTS – A SHIPBUILDER'S VISION

As part of the data collection process conducted during this effort, members of the DRB were asked to apply their shipbuilding experience and brainstorm a vision for how an advanced integrated system for strike-up/strike-down might function on various future platforms. This appendix is that vision for Small Surface Combatants and in no way is it intended to represent the views or opinions of the shipbuilding industry as a whole or the respective NAVSEA program office. It is provided here as background information and is intended to provide the reader with a better understanding of shipboard internal cargo movement challenges and potential solutions.

Small Surface Combatants

Strike-Up/Strike-Down for smaller surface combatants ships can take advantage of many of the technologies being pursued under the ExLog FNC for Shipboard Internal Cargo Movement. The over arching platform requirement that requires advances in the Strike Up/Strike Down area is reduced manning for both specific work tasks and the overall ship manning. Manning associated with Strike Up/Strike Down, and ultimately overall ship manning can be positively impacted by well thought out arrangements, technology innovation, and increased automation.

Ship arrangements that minimize stores, weapons, or cargo movement from point of receipt to stowage, and from stowage to point of use, can offer significant manpower savings through reduced material handling. Technology innovation that improves carrying capacity or throughput can reduce the required manning and duration of most given material transfer evolutions. Reduced maintenance technologies will not only take less time for maintenance, but will improve system availability. Automation will enable the material transfer process to be as hands-free as possible from point of receipt to stowage and from stowage to point of use.

The technologies reviewed can be scaled to suit a variety of platforms, small surface combatants ships included. Some specific examples follow:

- AWE/LEDT - similar elevators or in the case of small surface combatants, scaled down elevators (i.e., pallet sized) can significantly aid material movement onboard these ships. Moving material to stowage or point of use in the largest possible container can minimize handling time.
- Omni-directional vehicle/HAT can minimize manning required to move material about the ship. HAT can significantly reduce the effort of material handling.
- Standardized packaging such as NAVSTORS or RO-PAC can aid stowage and retrieval and make a simpler form of ASRS possible.
- Package identification from point of receipt to point of use can automate inventory management including retrograde stowage aids.

If taken to a proper level of maturity, current small surface combatant programs could make use of many of the proposed technologies through backfit. New surface combatant programs such as DD(X) and LCS will require some improvement in Strike Up/Strike Down area to satisfy the aggressive manning objectives of the Programs.

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APPENDIX K: SUSD FOR AMPHIBS – A SHIPBUILDER'S VISION

As part of the data collection process conducted during this effort, members of the DRB were asked to apply their shipbuilding experience and brainstorm a vision for how an advanced integrated system for strike-up/strike-down might function on various future platforms. This appendix is that vision for Amphibious Ships and in no way is it intended to represent the view or opinions of the shipbuilding industry as a whole. It is provided here as background information and is intended to provide the reader with a better understanding of shipboard internal cargo movement challenges and potential solutions.

Horizontal Movement for Strike-Down

VERTREP (Vertical Replenishment)

VERTREP is performed by helos carrying pallets from the supply ship to the amphibious ship. The maximum weight of a pallet is increasing from 3,000 lbs to 4,000 lbs. There will be larger loads placed on pallets when building up of FIULs (Fleet Issued Unit Loads) ashore.

When the cargo lands on the Flight Deck, personnel are needed to detach the helo hoisting rig from the cargo. Netting may need to be reattached for return to the supply ship. When the cargo detaches from a helo, an automatic load release may help reduce the manpower requirements.

In the near future, the Fleet may want to use an ODV (Omni Directional Vehicle) with HAT (Human Amplification Technology) where a man can walk large loads and place them on an elevator platform. This will look like a boy trailing a large wagon behind him.

The ODV will have the ability to lift the load off the deck and move to the elevator. The ODV will be capable of instantaneous sideways or angular movement, and can rotate within its own footprint. To compete with a man driving a forklift, the ODV should be capable of carrying a larger load at a fast walking rate and provide more maneuverability than a man driving a forklift.

In the future, an ODV may be able to drive to the elevator autonomously or by itself. This will allow a vehicle with pallets or a QUADCON to automatically transit through the ship to the cargo hold/magazine.

For strike down, an ODV should not have the capability to drive onto the elevator. The ODV should be able to drop off its cargo onto a mobile platform or the elevator platform itself. This will allow the ODV to return to the VERTREP drop off area to pick up more cargo.

CONREP (Connected Replenishment)

The types of cargo for CONREP include containers, quadcons, and pallets.

After the cargo lands on the deck in the replenishment area, an ODV picks it up and places it on the ODV platform. A method to secure the cargo to the platform must be provided. Manpower to lash down the cargo to the ODV platform does not appear to be the answer. The restraint system should be automatic and part of the ODV design.

The design of an ODV to carry 4,000 lbs may be easier than the carriage of a 12,000 lbs quadcon due to smaller power requirements. However, the quadcon has the advantages of using existing container fittings. Existing container spreader beams have mechanisms that latch onto a container. There are also intelligent spreader beams that can adjust to the container size. These could be adapted for quadcons in an ASRS.

Pallet Handling

There are no advanced pallet handling systems being used on commercial ships that handle pallets for movement internally. They are designed to load and unload from a pier.

Pallets will land on the deck and be handled by an ODV and brought to the storage area for the ASRS system. It would be difficult to land on an ODV at sea unless a large platform is provided. If this is done, there will be a need to secure the cargo to the platform without dunnage or lashings. To secure the cargo, a system using horizontal angle irons that comes up and squeezes the cargo may be possible. This may crush the cargo unless steel containers or boxes are used.

Pallets require personnel to rig slings. To lift pallets from above, a spreader is needed above the pallet for lifting from the bottom forklift pockets. This will need to be done manually such as the systems designed for the cargo monorail.

Vertical Movement for Strike-Down

Common Elevator Design

The development of a common improved elevator design could be used on all types of vessels and should be scalable and capable of backfit. The only way to achieve future throughput requirements may be through parallel elevator processes. These processes would occur simultaneously:

- Load at upper (transfer) deck
- Elevator transiting vertically and removing itself from vertical trunk.
- Unload at appropriate Hold or Magazine Deck level.

Waiting for an elevator slows down cargo throughput. An improvement in elevator cycle time is needed. The ability to operate an elevator in a manner similar to continuous operation will help throughput. An ODV should have the capability to communicate with the elevator to indicate that it is waiting at a platform with a load. The elevator should arrive empty ready to accept the cargo load.

The elevator design may be a circular type with two trunks or one trunk with moveable platforms. Multiple carriages could be located on the circular track, greatly improving cargo movement time. Ship arrangements allow access to elevators in two adjacent holds.

Elevator will have platforms that can move in or out of the trunk. They will not travel along the deck. There will be a moveable platform at each deck level with elevator openings. The platforms will be waiting for loads to be placed on it or it may be loaded with cargo waiting for the elevator to arrive. When the elevator arrives at the deck level and opens, the platform with pallets or other loads will drive into the elevator. These platforms may also be used as transfer tables when they do not have the ability to move into the elevator trunk.

Using conveyors for cargo movement would be an interesting near term solution to improving cargo flow. An elevator platform could have a conveyor. The depth may have to be increased to provide for a conveyor. The deck outside the elevator will also have a conveyor. These conveyors will need to align with each other.

Offset Elevator Design

Part of the Advanced Weapons Elevator (AWE) development includes the design of a ballistic hatch to integrate with the new elevator and development of a mobile elevator carriage. Amphibious ships do not

have ballistic hatch interfaces with their Cargo/Weapons elevators that an Aircraft Carrier has. However, to increase the survivability of an LHD type ship, its design may want to have offset elevators similar to Aircraft Carriers. This may also make it easier to have a below deck bomb farm inside the hull of the ship instead of outside on the Flight Deck outboard of the island.

To take advantage of the benefit provided by offset elevators, LEDT technology could be used for continuous flow of an elevator platform. Linear motor technology would move a carriage with a full load vertically, and then transition to horizontal movement and back to vertical movement.

Bomb Assembly and Strike Up

To perform bomb assembly in holds, HAT technology will be beneficial if there is one machine capable of lifting the bomb for assembly work and using the same machine for transport. The HAT machine would be able to go onto and off of an elevator, travel across the Flight Deck and load a bomb onto an aircraft. A HAT machine that can handle multiple bombs for assembly and transport to an aircraft should be a design goal. A man on the Flight Deck will be waiting to bring the bombs to the plane for loading.

HAT allows a single sailor to quickly position a weapon onto an aircraft with force feedback to allow the sailor to feel the attachment of the weapon. This would replace the manpower required to manhandle weapons onto an aircraft. Presently, HAT technology is designed for control by one man.

To take advantage of HAT, the method for getting the bomb and its components out of stowage for assembly needs to be addressed. An ASRS system may be the solution to this.

Strike Up of Palletized LFORM Cargo

An ODV may be used to lift and carry LFORM cargo. It should have the capability to move with the load and place it onto the elevator or mobile platform. A mobile platform will require deck area in way of the elevator. In the cargo/ammo hold, additional area will also be needed for bomb assembly.

Offload of the LFORM cargo from the elevator may also be achieved using mobile platforms or conveyors. ODVs will be used to drive to staging areas in Upper Vehicle and onto LCACs. The Well Deck may also be used for staging vehicles and cargo after the initial preload on the LCACs departs the vessel. The speed of ODVs must compare favorably with not only forklift trucks but also bridge cranes or cargo monorail systems. ODVs must be able to drive safely with cargo up and down relatively steep ramps.

The ODV may provide improvement in the overall time for the material handling process by eliminating transfer points, not just its speed of travel. It may decrease the number of transfer points or shorten steps in the cargo handling system. The decrease in the number of transfers whether performed by machine or manpower may be a measure of improvement.

ASRS (Automated Storage and Retrieval System)

The Automated Storage and Retrieval System (ASRS) is a selective offload technology based on commercial material handling and warehousing systems. One ASRS key issue is cargo restraint. Current technologies employed in commercial warehousing do not satisfactorily address these issues in a marine environment.

Securing cargo to an ASRS carriage and in its stowage racks needs to be addressed. It would be difficult to do this without some sort of standardization in cargo packaging. Securing cargo in an ASRS using

chains and/or stanchions requires manpower that defeats the purpose of an automated system. Instead of securing individual cargo loads, an ASRS that locks and unlocks a cargo row using a bracing system may be needed.

An ASRS system may be more suitable for installation in the more open, larger holds on an MPF(F) ship than the magazines or holds on a CVN or L ship.

Automated Stowage and Retrieval Systems (ASRS) are in common use ashore but there are no sea going systems. A system that is space efficient, utilizes shipboard power, and enables effective and efficient stowage with selective offload should be developed. Performing automated warehousing in the confined spaces on a ship at sea is a major challenge.

An ASRS system that handles pallets will probably require a redesign of pallets to provide strong points for restraint. Unless pallets are secured by stanchions or chains in stowage, pallets will need to be reinforced in restraint areas. Pallets stowed in the rows of an ASRS system may possibly be secured by raising a locking bar to secure all pallets at the same time. Pallets may not be designed for stacking like containers due to possible crushing of the pallet contents so the ASRS will need stowage racks.

To provide selective offload without using an ASRS system will require aisles and narrow aisle forklift trucks. Manpower will be needed for unlashing and movement with forklift trucks.

Quadcons

On an amphib ship, quadcons do not carry more than 6,000 lbs max due to equipment and arrangement limitations. The decision to go to Heavy UNREP for 12,000 lbs transfers appears to be aimed at transferring quadcons at sea from a supply ship to an L ship or the MPF(F) ship.

Four quadcons can be bridged to make up to 20' container unit. However, in comparison to normal 20' containers, there may be a limit as to how deep you can stack 20' containers that consist of quadcons only on a containership.

On the containership, you could bring the 20' quadcon container out on the open deck using shipboard cranes. The bridging pieces between quadcons would be disconnected and each quadcon sent over by the 12K heavy UNREP system.

Containers need to land in an open area on the weather deck or below. The containers will need to be handled and stowed at sea, which is a very difficult challenge. Internal cargo handling systems for handling containers would be cumbersome. Unstuffing the contents of the container and sending the container back to the supply vessel will require time and shipboard manpower that is not available.

If quadcons need to be unpacked for shipment ashore, then systems or procedures will be needed for opening quadcons and transferring its contents to an assembly area for shipment ashore.

Container handlers that lift from above may be provided in lieu of forklift trucks. A container handler, such as manufactured by Kalmar, will have a spreader beam for lifting the container.

Quadcons, that are not handled by forklift truck or container handler onboard a ship, will have to be lifted by overhead systems and placed in cell guides or container deck fittings for securing.

Expeditionary Logistics
Future Naval Capability

Strike Up
Down

Shipboard Internal
Cargo Movement